SEWAGE AND INDUSTRIAL WASTES

(Formerly Sewage Works Journal)

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

Special Features

Sludge Conditioning and Filtration—Genter

Citrus Waste Treatment by Activation—McNary et al.

Lime Neutralization and Sludge Volumes—Faust et al.

Cannery Waste Lagoon Odors—Jones

Macro-Invertebrates as Indicators—Gaufin and Tarzwell

Hatfield Operation Award

JULY, 1956—VOL. 28, No. 7

Make Plans to Attend

29TH ANNUAL MEETING

OF THE

FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

IN CONJUNCTION WITH

CALIFORNIA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

STATLER HOTEL

LOS ANGELES, CALIFORNIA

October 8-11, 1956

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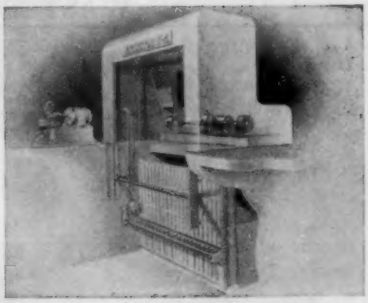
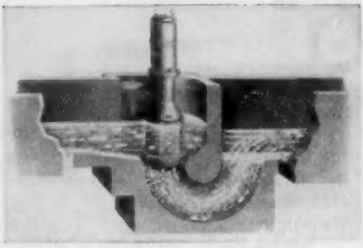
For Sewage Flows From .005 to 250 MGD Per Machine Installed In A 6" Pipe, A Basin Or A Rectangular Channel Section.

The greater flexibility and wide applicability of comminution made possible by the equipment illustrated here is the result of Chicago Pump Company's original development of comminution and the Comminutor and its 20 years of experience in over 4000 installations of exclusively successful comminution.

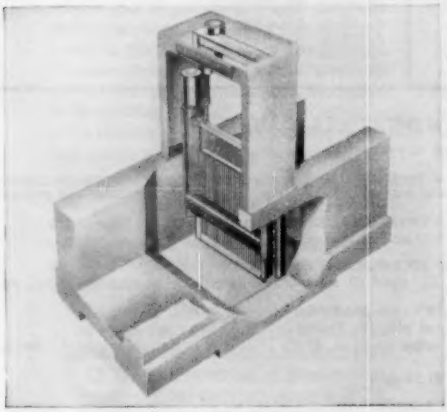
**Continuous screening and subsurface cutting of coarse sewage material without removal from the sewage flow, eliminating unsightly mess, nuisance and odor from screenings.*



Model "A"' Barminutor Screening and Comminuting Machine. Designed for use in rectangular channel sections 4 to 12 feet wide, sized for flows of 10 MGD and upwards.



The Comminutor Screening and Comminuting Machine. Designed for use in hydraulically designed feeder basin, sized for flows from .175 to 25 MGD per machine.



◀ Model "B" Barminutor Screening and Comminuting Machine. Designed for use in rectangular channel sections 1 to 3 feet wide, sized for flows from .09 to 15 MGD.

Model 7B Comminutor Screening and Comminuting Machine. Designed for use in 6" or 8" sewer pipe, sized for flows from .005 to .175 MGD per machine.

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A monthly Journal devoted to the advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes, and the design, construction, operation and management of such works.

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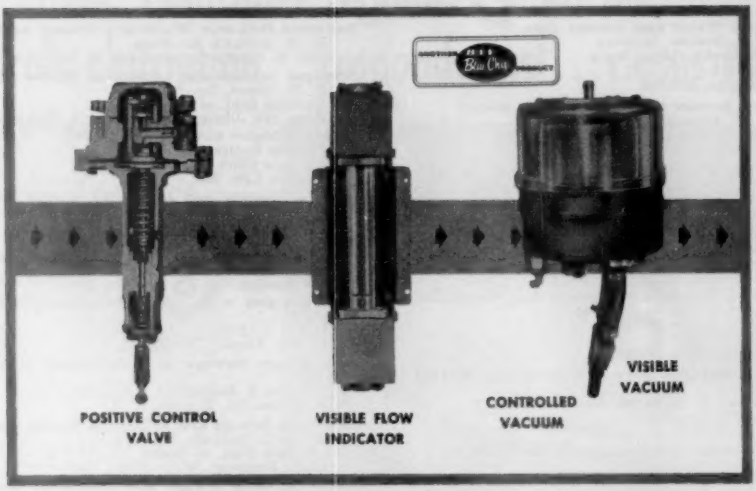

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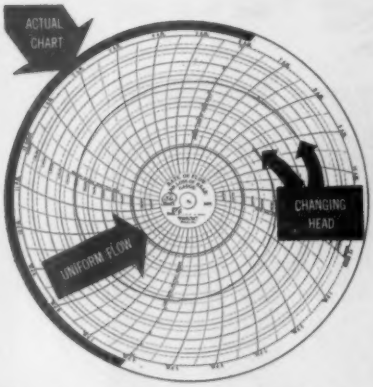
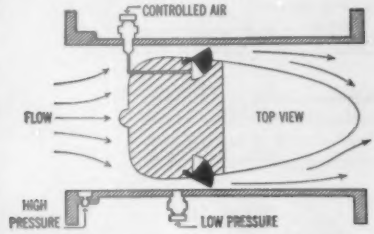
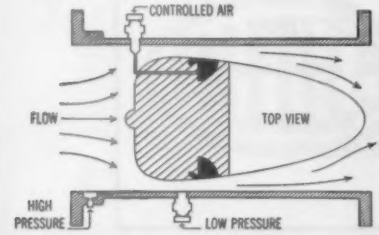
Modulair® Controller regulates plant discharges, controls elutriation...responds fast...closes tight!



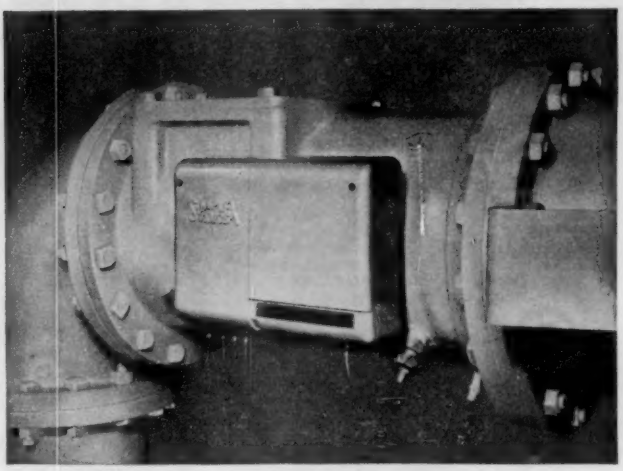
Here's proof that the new Simplex Modulair Controller responds instantly to changes in operating head . . . automatically holds flow at desired rate. Chart from Modulair installation shows head increasing 75% while flow forms almost perfect circle.



How Modulair works! Pipe-like casting with annular Venturi throat houses streamlined inner body with corded-rubber modulator (black) that expands and contracts pneumatically to control flow. When operating head rises, modulator expands automatically to restrict flow to set rate.



When operating head falls, flow tends to decrease—changing the Venturi differential. Sensitive Modulair compensates immediately. Modulator contracts—automatically keeps flow at rate desired.



Compact . . . easily installed Modulair is only 2 to 3 pipe diameters long! Fits wherever a piece of pipe can fit . . . in any position, horizontal or vertical—simplifying piping layout. Modulair comes in 4" to 24" cast iron pipe sizes with corrosion-resisting fittings. Corded-rubber throttling element that's as tough as a truck tire has given 30 years' wear in accelerated life-tests.

Accuracy! In 4 years of field performance, Modulair shows an accuracy in control that exceeds today's most exacting demands. It brings you sensitive, accurate flow control under wide ranges of operating head. And is tight-closing—eliminating need for separate shut-off valves.

Minimize maintenance! With Modulair's single tap design, there's no place for air to accumulate . . . no place for sediment or sludge to lodge and interfere with accuracy. The only moving part inside pipeline is non-corrosive rubber throttling element. Pneumatic poise element is simple, rugged. There are no line valves, no pilot valves, no pistons, no valve shafts, no stuffing boxes to pack!

Lower first cost. Modulair's low head loss means lower operating-head requirements . . . permits vertical compression in plant design and lower costs in plant construction.

Completely pneumatic! No intermediate hydraulic steps! No pilot valves! No hydraulic cylinders! Air loading pressure is applied *directly* to the flow controlling element.

Automatic operation! Modulair works with control systems of any type to give you remote rate control or master pneumatic control that's fully automatic.

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Kentucky-Tennessee Industrial Wastes and Sewage Works Assn.	Hotel Patten Chattanooga, Tenn.	Sept. 17–19, 1956
Georgia Water and Sewage Assn.	Hightower Textile Bldg. Georgia Inst. of Technology, Atlanta, Ga.	Sept. 19–21, 1956
South Dakota Water and Sewage Works Conference	Aberdeen, S. D.	Sept. 19–21, 1956
Missouri Water and Sewerage Conference	Hotel Governor Jefferson City, Mo.	Sept. 30–Oct. 2, 1956
Abwassertechnische Vereinigung	Dusseldorf, Germany	Oct. 3–5, 1956
North Dakota Water and Sewage Works Conference	Lewis and Clark Hotel Mandan, N. D.	Oct. 3–5, 1956
Pacific Northwest Sewage and Industrial Wastes Assn.	Boise, Idaho	Oct. 4–6, 1956
Canadian Institute on Sewage and Sanitation	Prince Edward Hotel Windsor, Ontario	Oct. 29–31, 1956
West Virginia Sewage and Industrial Wastes Assn.	West Virginian Hotel Bluefield, W. Va.	Oct. 31–Nov. 2, 1956
Nebraska Sewage and Industrial Wastes Assn.	Castle Hotel Omaha, Neb.	Nov. 1–2, 1956
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Florida Sewage and Industrial Wastes Assn.	Daytona Plaza Hotel Daytona Beach, Fla.	Nov. 11–14, 1956
North Carolina Sewage and Industrial Waste Assn.	Charlotte Hotel Charlotte, N. C.	Nov. 12–14, 1956

TWENTY-NINTH ANNUAL MEETING

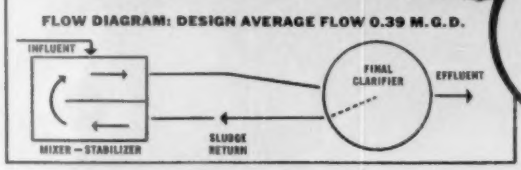
Federation of Sewage and Industrial Wastes Associations
in conjunction with
California Sewage and Industrial Wastes Association
Statler Hotel, Los Angeles, California
October 8–11, 1956

INFILCO *High-Rate* SEWAGE TREATMENT

twice as fast in half the space

Sewage plant of Washington County Sewer Improvement District No. 1, at Bartlesville, Okla., is compact and efficient with INFILCO equipment.

Engineering by Wood & Craig Consulting Engineers, Tulsa, Okla.



Only 5 to 6 hours are required for throughput in the BIOSORPTION® high-rate activated-sludge treatment plant equipped by INFILCO—as compared to 10 to 12 hours for conventional equipment. Main components of the Bartlesville installation include a GRIDUCTOR® comminutor, a mixer-stabilizer with COLAFLEX® diffusers, WS clarifier and floating cover for digester. Overall results are excellent. Here are typical figures.

Period	Ave. Flow MGD	Average B.O.D. (p.p.m.) Raw Sewage	Final Effluent	% Removal	Suspended Solids (p.p.m.) Raw Sewage	Final Effluent	% Removal
1/14-2/3 '55	0.253	197	18	90.8	225	20	91.0

If your problem involves greater volume in less time from less space—*at lower cost*—consult INFILCO because INFILCO KNOWS HOW to help you solve it. Over 60 years of experience and the most complete and advanced line of equipment are available to you. Write today for full information on the interesting Bartlesville installation and Bulletin No. 6550-SI-25.

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hands, too)

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"Since 1948, when our Worthington comminutor was installed, it has operated successfully with only routine maintenance. The comminutor's reliability has proved a real blessing for our plant operation."

So says Ed Molitor, Plant Superintendent, about the 25-inch comminutor in service at Madison-Chatham, N. J., Joint-Meeting Sewage Treatment Plant.

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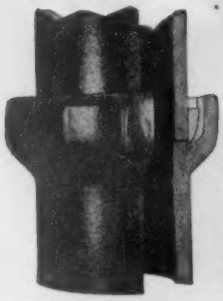
AMVIT* JOINTED CLAY PIPE gains wide acceptance, more than 60 major installations completed in 1955



Never before has a new product gained such wide acceptance and usage in such a short period of time

In the first year since Amvit Jointed Clay Pipe was introduced more than 60 major installations have been completed with outstanding results. Such pioneer cities as Dayton, Ohio, Camden, New Jersey, Otsego, Michigan, Victor, New York, have installed their second and third Amvit Jointed sanitary lines.

Prevents Infiltration

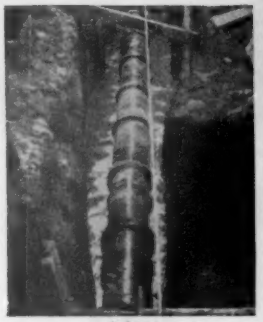
Field tests from these installations show that ground water infiltration can be controlled and prevented—thus reducing pumping and treatment plant costs. Amvit is a compression type joint on the ball and socket principle. Nothing can enter the line after it is complete.

Quick Installation Saves Labor

Since no other material such as caulking, joint compound, hot-pots or ladles are needed to make the Amvit Joint, installation is quick and easy. The joint is on the pipe delivered to the job ready to use. Savings with Amvit Jointed Clay Pipe mean *lower cost of pipe in place* when the line must meet a rigid test.

Amvit Jointed Clay Pipe, in sizes 4" through 24", together with all fittings is available for immediate delivery in the Northeast and Central States.

For more information, write or call American Vitrified Products Company, National City Bank Building, Cleveland, Ohio, or our office nearest you.



Indiana

New Jersey

Michigan

Wisconsin

Illinois

*T M. Registered Patents Pending

SINCE 1900

American Vitrified Products Company

CLEVELAND OHIO

MANUFACTURERS of: Clay pipe, flue liners, clay liner plates and concrete pipe.

Plants Across the Nation...Brazil, Indiana • Chicago, Illinois • Cleveland, Ohio • Crawfordsville, Indiana • Detroit, Michigan • East Liverpool, Ohio Fenton, Michigan • Grand Ledge, Michigan • Lisbon, Ohio • Los Angeles, California • Milwaukee, Wisconsin • South Bend, Indiana • Uhrichsville, Ohio

Sewage SLUDGE

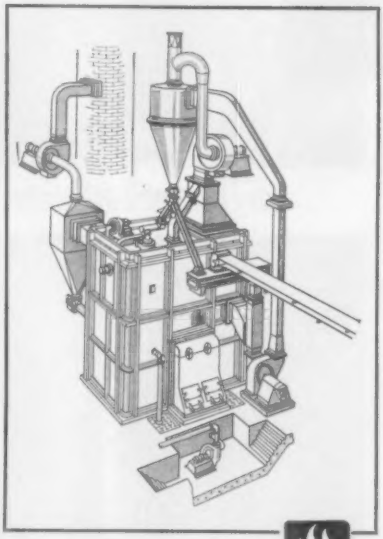
BURN IT!
SELL IT!

You can do both with the C-E Raymond System

For versatility alone, you can't beat the *C-E Raymond System of Flash Drying and Incineration!* With it, you can incinerate sewage sludge to a sterile ash . . . or flash-dry it to a fertilizer and soil conditioner that is readily marketed. Either operation can be performed alone, or combined in any proportion.

In either case, high-temperature deodorization of stack gases is available.

Whether you wish to incinerate or dry—look to the C-E Raymond System for the effective end to your sludge disposal problems. For specific recommendations for your community, get in touch with a C-E specialist at the office nearest you. He will be happy to work with you and your consultant.



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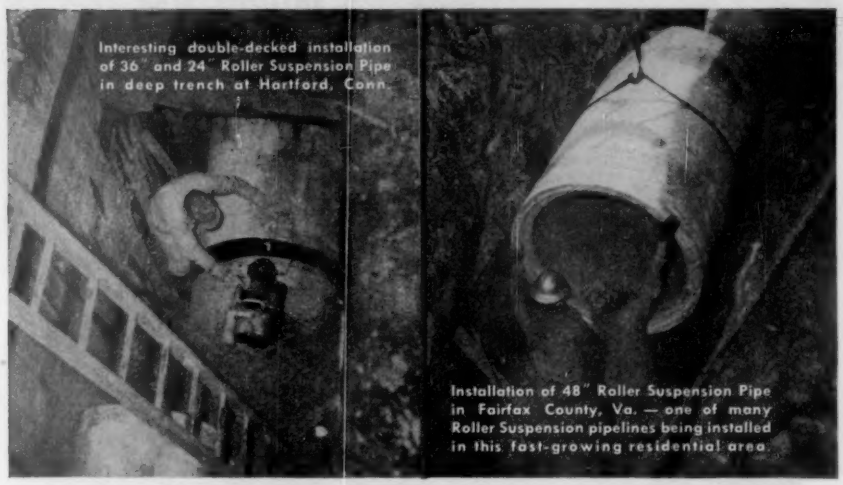
ALSO FLASH DRYING AND INCINERATION SYSTEMS FOR INDUSTRIAL WASTE DISPOSAL

FOR EXCEPTIONAL STRENGTH
LOCK JOINT
ROLLER SUSPENSION PIPE



Interesting double-decked installation of 36" and 24" Roller Suspension Pipe in deep trench at Hartford, Conn.

Installation of 48" Roller Suspension Pipe in Fairfax County, Va. — one of many Roller Suspension pipelines being installed in this fast-growing residential area.

The unique manufacturing process by which Lock Joint Roller Suspension reinforced concrete sewer and culvert pipe is produced permits the use of a low water-cement ratio and a high proportion of stone in the mix. The concrete obtained by this system is unusually strong and resistant to abrasion.

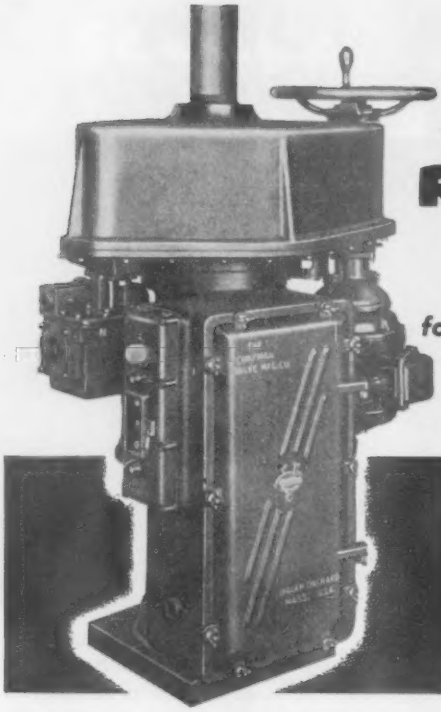
Roller Suspension Pipe of equal wall thickness and steel area to cast or machine made concrete pipe consequently offers a considerable premium in strength and durability.
For projects requiring exceptionally rugged sewer or culvert pipe, specify Lock Joint's ultra-modern ROLLER SUSPENSION PIPE.

LOCK JOINT PIPE CO.
East Orange, N. J.

Sewer and Culvert Pipe Plants:

Kenilworth, New Jersey
Hartford, Connecticut
New Haven, Connecticut
Beloit, Wisconsin
Chicago, Illinois
Rock Island, Illinois
Valley Park, Missouri
N. Kansas City, Missouri
Tulsa, Oklahoma
Oklahoma City, Oklahoma
Wichita, Kansas
Denver, Colorado
Cheyenne, Wyoming
Casper, Wyoming
Tucumcari, New Mexico
Hato Rey, Puerto Rico
Ponce, Puerto Rico
Caracas, Venezuela

Also Great Lakes Concrete Pipe Company with plants at Buffalo, N. Y. and Henrietta, N. Y.



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RUGGED...
CHAPMAN'S
MOTOR UNIT
for Valves, Floorstands and Sluice Gates

Floorstand equipped with Motor Unit . . . control panel, motor, limit switch and push button station.

Simple, durable mechanism of Chapman's Motor Unit. Handwheel remains stationary during motor operation.

Chapman Motor Units have fewer components than any other units, providing greater dependability, much lower maintenance costs.

There are only two pinions and two gears in the motor reduction train: drift is eliminated and lash is negligible. Your valves seat tight, but not too tight. Operation is *always* smooth and trouble-free.

You can mount the Chapman Motor Unit in any position, at any angle required. The rugged stub-tooth gears require no grease or oil bath . . . yet run smoothly, quietly, with minimum wear.

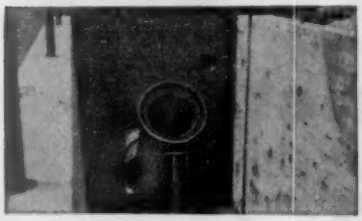
Weatherproof and steam tight, Chapman's floorstand units are shipped completely wired, ready to connect to your power leads, for easy, rapid installation. This modern motor unit is dependable and economical. Send for *new* catalog No. 51.

The CHAPMAN Valve
Manufacturing Company
INDIAN ORCHARD, MASSACHUSETTS

CLAY PIPE *SOLVES* Acid Handling Problems at New Petro-Chemical Plant

THE STANDARD OIL CO. installed several thousand feet of Vitrified Clay Pipe to handle acid wastes in its new $17 million petro-chemical plant at Lima, Ohio. The plant produces anhydrous ammonia, urea, nitrogen solutions, and nitric acid.

NITRIC ACID TANK on the left discharges into the 18-inch Clay Pipe line shown being installed. Clay Pipe is completely unaffected by corrosive chemicals.



THE SOHIO PLANT has its own sewage treatment facilities. Acid is neutralized in this pit where a Vitrified Clay Pipe overflow line drains off the neutralized waste into a conventional sewerage system.

CLAY PIPE
Offers a variety of jointing methods and materials to meet every need. For this acid-handling application, engineers specified a special hot-poured joint, with quick-setting and high corrosion resistance characteristics.

Directing the project for Sohio were: *F. J. Sanders, Technical Manager; H. F. West, Chief, General Engineering Division; Ted Jakim, Field Engineer.* Pipe was installed by: *A. G. McKee Co.* Other major contractors on the job included: *M. W. Kellog Co., Chemical & Industrial Co.; Vulcan Copper & Supply Co.*

Vitrified CLAY PIPE

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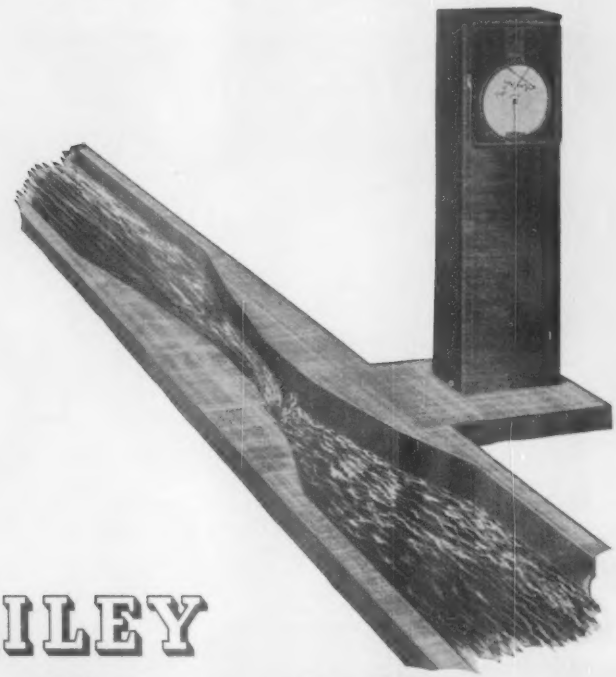
Progress in Public Health - Through Clay Pipe Research

C-1155-SA



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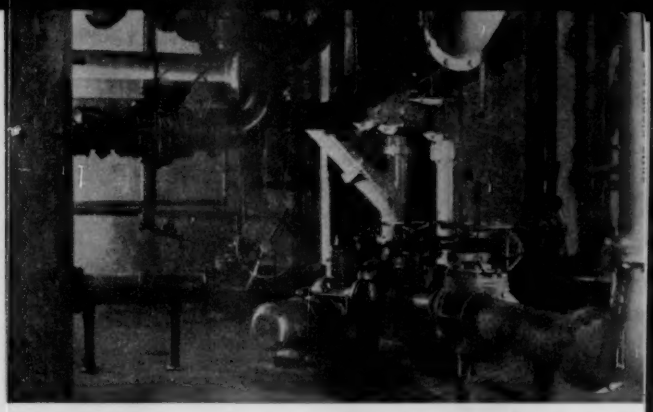
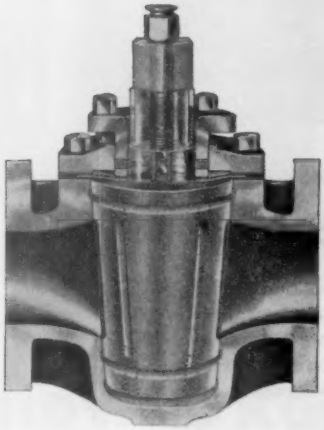


ROCKWELL-Nordstrom VALVES

for any wastes service



40th ROCKWELL YEAR

of lubricated plug valve leadership

The photo above shows Rockwell-Nordstrom valves on sump discharge and supernatant lines at one of the country's largest sewage disposal plants. 40 years of experience have proven that Rockwell-Nordstrom valves allow complete versatility of installation, dependable flow control on any wastes service, and lowest maintenance cost.

Rockwell-Nordstrom valves are ideal for wrench, chain wheel, gear, floor stand and power operation because *quarter-turn operation* is two to five times faster than ordinary valves. Streamlined flow passages minimize pressure loss on low pressure sewage gas as well as heavy sludge. The *tapered plug* is "cushioned" on its seat by pressurized lubricant for instant, smooth operation. Lubricant in Rockwell-Nordstrom valves also eliminates metal-to-metal wearing friction. Maintenance and down time costs are lower than any other valve.

Write for more information on how you can have dependable, trouble-free valve service at lowest cost with Rockwell-Nordstrom valves.

Canadian Valve Licensee: *Peacock Brothers Limited*

ROCKWELL-
Nordstrom
VALVES
Lubricant Sealed for Positive Shut-off

Rockwell Manufacturing Company
Pittsburgh 8, Pennsylvania

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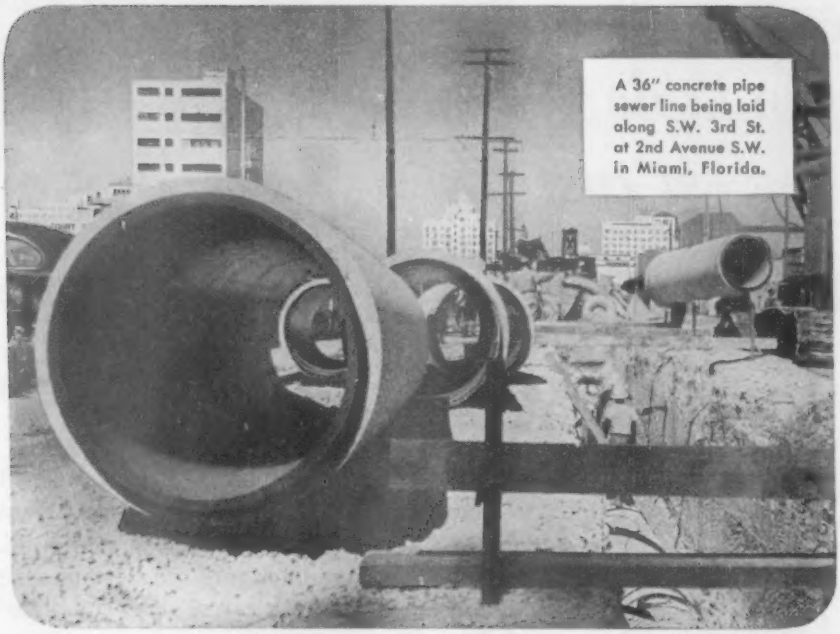


Miami, Florida, builds gigantic sewer system with reinforced *CONCRETE PIPE*

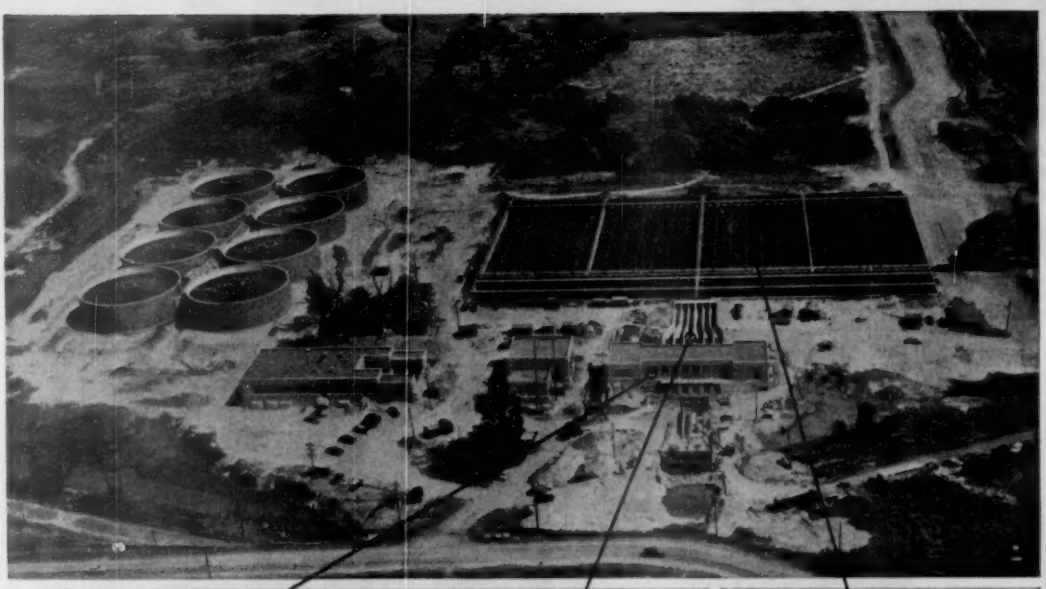
Miami is investing $27 million to halt the pollution of the Miami River and Biscayne Bay caused by the discharge of raw sewage into these waters. The project includes a treatment plant on Virginia Key, a 3-mile sub-aqueous sewer line, an ocean outfall, six pumping stations and huge intercepting sewers. In all, 6½ miles of reinforced concrete pipe, 24 in. to 108 in. in diameter, will be used.

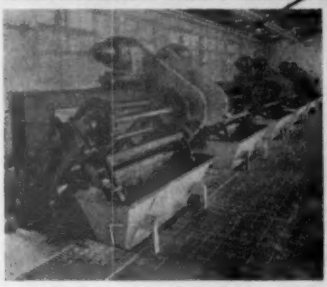
Like Miami, hundreds of cities use concrete pipe for long, economical sewer service. It's a fact that concrete pipe sewers have given ***low-annual-cost*** service for 75, 85, 100 years and more.

Concrete pipe has (1) the strength to withstand severe impact and to sustain heavy overburdens, (2) the smooth interior surface to resist abrasion and provide maximum hydraulic capacity and (3) the uniformly dense structure and tight joints to insure minimum infiltration and leakage in any pipeline service.

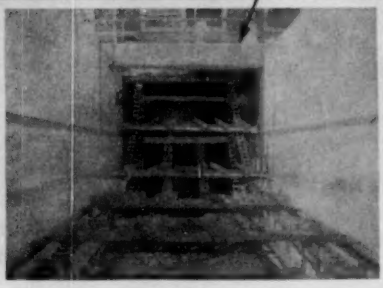
Concrete pipe is moderate in first cost, requires little or no maintenance and serves extra long. It delivers ***low-annual-cost*** sewer service.

PORTLAND CEMENT ASSOCIATION
33 West Grand Avenue, Chicago 10, Illinois
A national organization to improve and extend the uses of portland cement and concrete . . . through scientific research and engineering field work

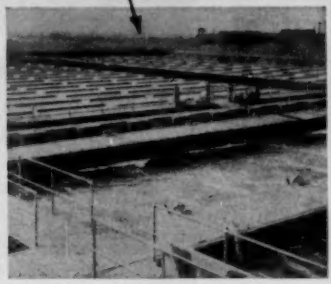




Six Link-Belt inclined bar screens, each with eight rakes, discharge screenings onto steel belt conveyor.



Sewage from grit and screen building flows into six grit channels, where grit settles and is removed by L-B grit collectors and washing-dewatering screw conveyors.



Primary settling tanks use Link-Belt longitudinal and cross collectors, scum skimmers and drives.

Philadelphia's Southwest Sewage Works demonstrates

how to keep treatment capacity ahead of population growth

FORESIGHT was a key element in planning this new Philadelphia sewage plant. It had to provide practical waste treatment for a population of 870,000 — yet be able to serve the estimated 1,200,000 expected by 1970. Working with city engineers, Link-Belt helped supply the efficient screens, grit collectors and sludge collectors to handle 136 mgd.

This $8 million plant is part of Philadelphia's ten-year, $80 million program for the elimination of stream pollution. Link-Belt Straightline Collectors were also chosen for the Northeast Works with a capacity of 125 mgd, completed in 1951 as the first phase in this huge project.

Whether you're concerned with large municipal or small industrial waste treatment . . . or need the finest in modern water purification equipment — count on Link-Belt to provide maximum efficiency at all flow conditions. Our engineers can call on a complete line of equipment . . . will work with you, your chemists and consultants.

LINK-BELT

SANITARY ENGINEERING EQUIPMENT

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13,941

Here's how an "*accident*" proved the ruggedness of the Fischer & Porter Chlorinator

Here's the true story of how one user decided the modern, rugged Fischer & Porter Chlorinator was his best buy.

"I was impressed with the F&P Chlorinator the minute your field engineer arrived."

"He pulled up to a loading dock in a truck and began to unload the chlorinator. When he had it at the back of the truck, he stopped and got back inside the cab as if to get something and then 'accidentally' let the clutch slip. The truck shot forward and the chlorinator toppled off the back of the truck and onto the cement floor."

"For a moment we all thought the equipment would smash into a hundred pieces—but it didn't. That just about sold us on it. Of course, we now realize the 'accident' was all part of the demonstration to show us how tough the F&P Chlorinator is."

No other chlorinator is built this way. No other chlorinator can take such punishment. The light weight, fibre glass cabinet is so rugged even such an "accident" won't harm it.

And what's more, this is only one true story of user satisfaction with the F&P Chlorinator. Everywhere users are adding their words of praise for this chlorinator.

In addition to the ruggedness of the unit, you get simplified operation, the absolute minimum of maintenance costs. As one user puts it, "We shudder at the thought of overhauling other chlorinator units, but it's a pleasure to bring the F&P unit into the shop. We know it will need very little maintenance work—and any work it does need will be 'child's play,' compared to the time and back-breaking labor spent on other chlorinators."

Users are saying these things. If you're not acquainted with the Fischer & Porter Chlorinator now is the time to get complete information. It won't cost you a penny, you won't be obligated in any way . . . and if you like we will arrange an on-the-spot demonstration for you anytime, anywhere. Write today for details. Fischer & Porter Company, 1176 Fischer Road, Hatboro, Pennsylvania.

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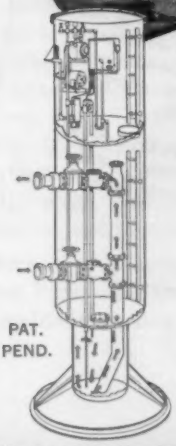

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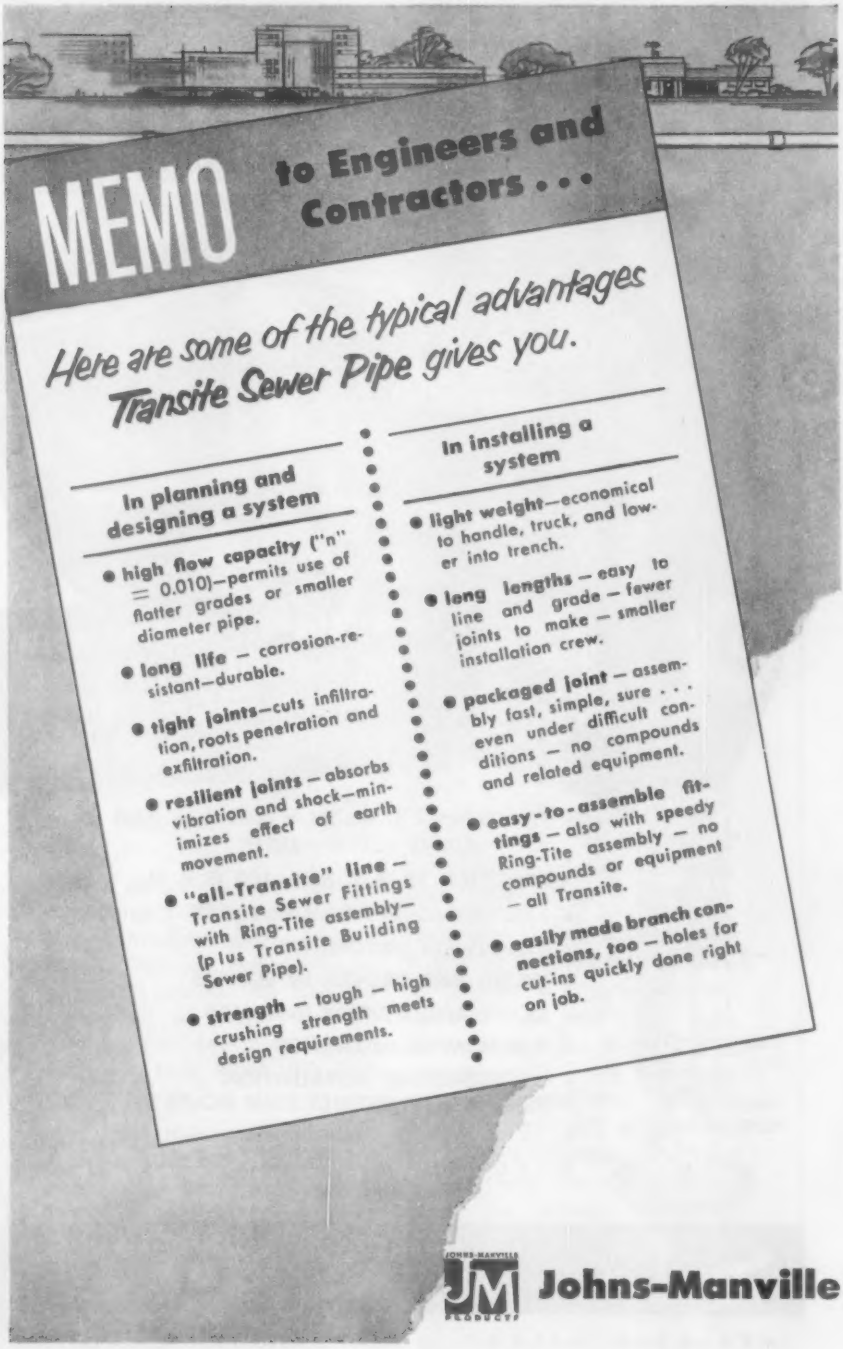
MEMO to Engineers and Contractors . . .
Here are some of the typical advantages Transite Sewer Pipe gives you.
In planning and designing a system
● high flow capacity ("n" = 0.010)—permits use of flatter grades or smaller diameter pipe.
● long life — corrosion-resistant—durable.
● tight joints—cuts infiltration, roots penetration and exfiltration.
● resilient joints — absorbs vibration and shock—minimizes effect of earth movement.
● "all-Transite" line — Transite Sewer Fittings with Ring-Tite assembly—(plus Transite Building Sewer Pipe).
● strength — tough — high crushing strength meets design requirements.
In installing a system
● light weight—economical to handle, truck, and lower into trench.
● long lengths — easy to line and grade — fewer joints to make — smaller installation crew.
● packaged joint — assembly fast, simple, sure . . . even under difficult conditions — no compounds and related equipment.
● easy-to-assemble fittings — also with speedy Ring-Tite assembly — no compounds or equipment — all Transite.
● easily made branch connections, too — holes for cut-ins quickly done right on job.
JOHNS-MANVILLE PRODUCTS
JM
Johns-Manville

Select

Transite® for more economical, tighter sewerage systems . . .

WHETHER a new sewerage system is being planned or additions to an existing one are being made . . . engineer and contractor alike will find a combination of qualities in performance-proved Transite Sewer Pipe that will fit their individual needs. They will find this holds true whether the local conditions call for (a) tight joints to protect against root growth and infiltration of ground water or (b) the strength and flow characteristics that mean definite savings in the design stage, during trenching and installation, and in operation as well.

For further information about Transite Sewer Pipe, write for Booklet TR-165A, Johns-Manville, Box 60, N. Y. 16, N. Y.

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with the RING-TITE® Coupling

greater handling economy

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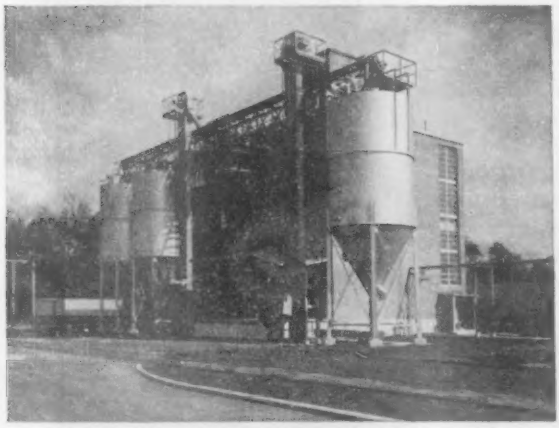

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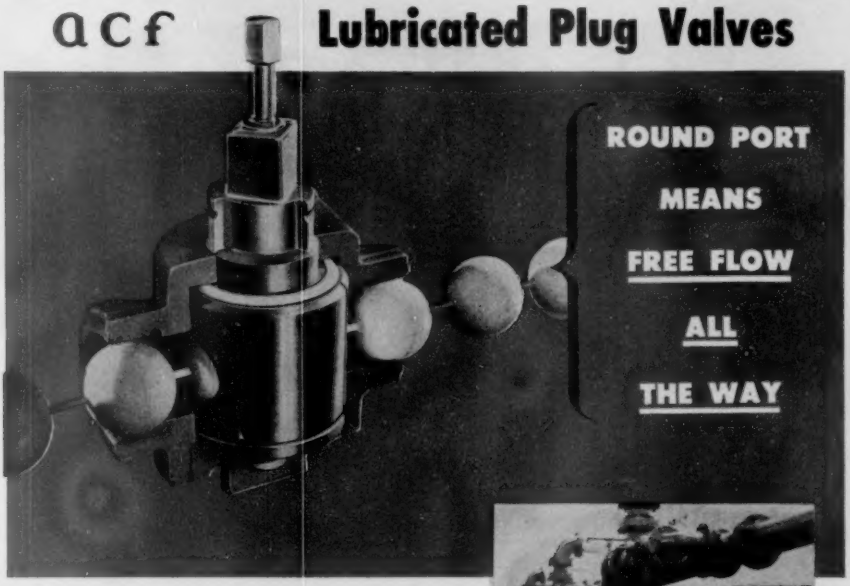
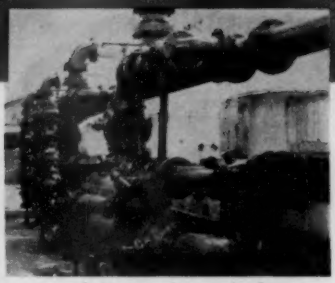
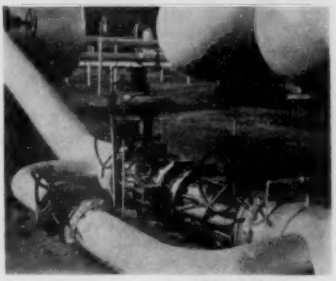




In salt water disposal plant.



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You get full volume, unrestricted flow throughout the entire piping system when you use QCf Round Port Valves.

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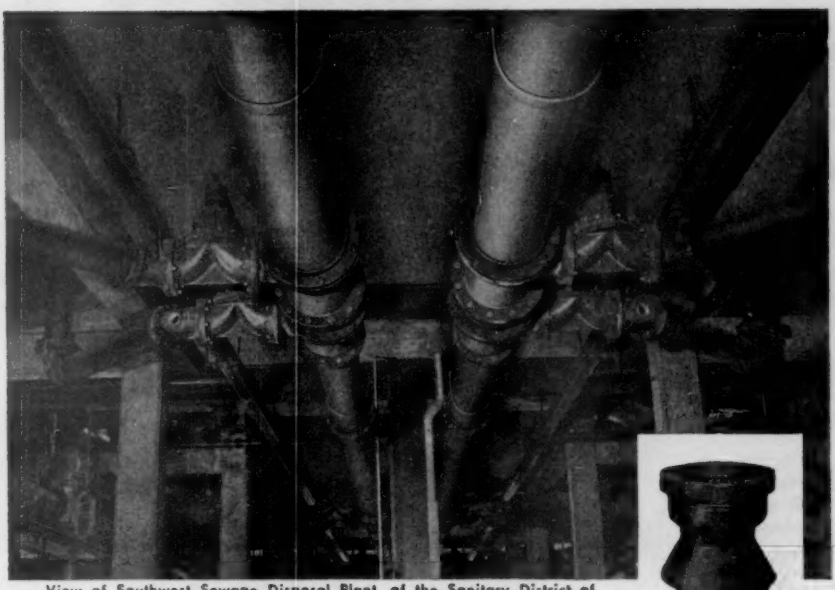

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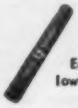

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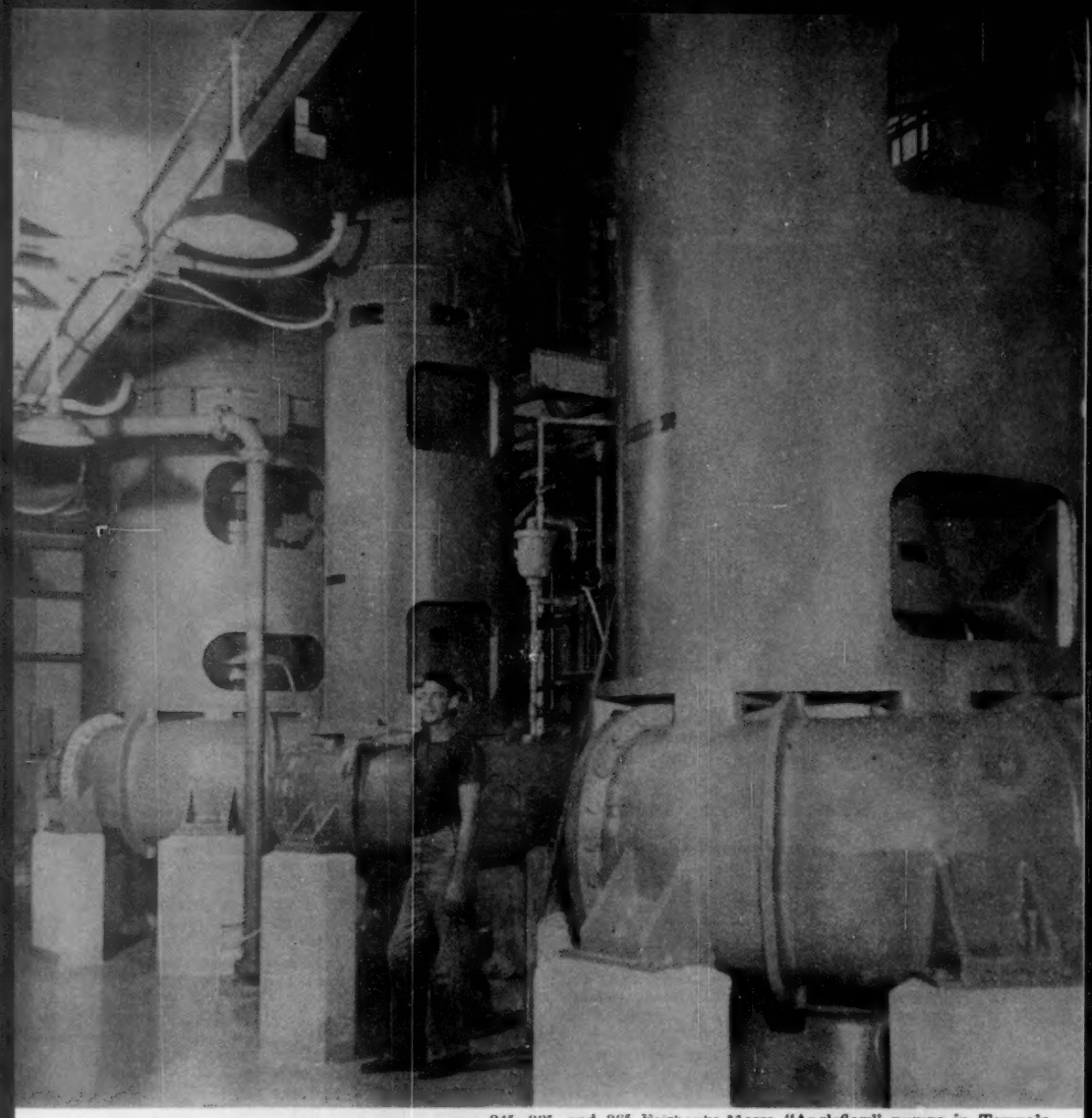

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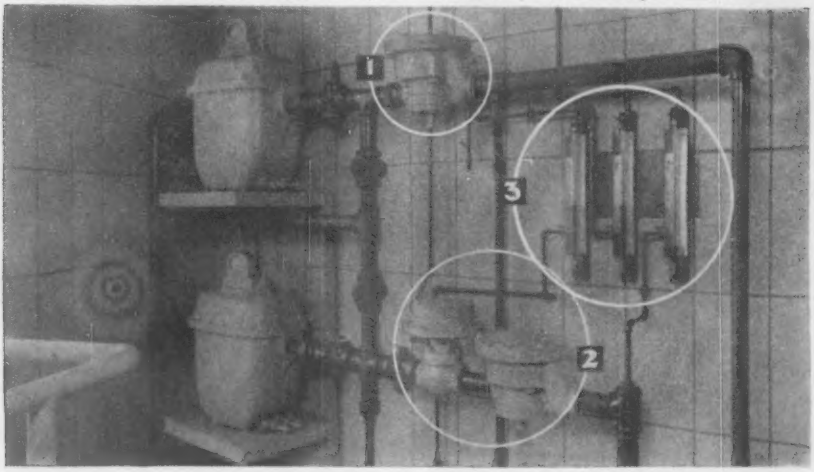
PFT Gas Safety Equipment in the Control Building at the new Morris plant. See description below.



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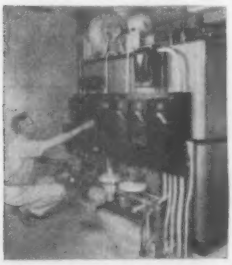

Plant Superintendent G. B. Reagen checks operation of the PFT #250 Heater & Heat Exchanger.

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SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 28 . July, 1956 Number 7

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Sewage Works

CONDITIONING AND VACUUM FILTRATION OF SLUDGE *

By Albert L. Genter

Consulting Engineer, Baltimore, Md.

In 1941 the writer (1) called attention to the fact that the sanitary engineer borrowed largely from certain industrial fields for his mechanical equipment and, due to the large amount of water and small amount of settleable solids present in the sewage he was treating, he soon learned to take the dewatering of the solids in stages; that is, plain sedimentation, thickening, sometimes digestion of the collected sludge in order to stabilize and render it inoffensive, draining it on sand beds, and finally by mechanical filtration and further evaporation.

Plain sedimentation removes 99.7 per cent of the total water, digestion and sand bed dewatering or mechanical filtration removes about another 0.3 per cent of the total water. This leaves about 0.04 per cent of the job of total dewatering to be done by those concerned with heat drying. As emphasized at the time (1), "The smaller the fraction of water to be removed becomes, the greater becomes the expenditure per pound of water and the more we talk about it." This illustrates the law of diminishing return.

In any industrial engineering field the instant the job is taken over where gravity can no longer work cheaply and rapidly enough, the more mental stir is created and the more money is spent. The very factors which influence plain sedimentation of settleable sewage solids likewise materially influence sludge dewatering in mechanical filtration or on sand beds. The use of various chemical agents for increasing settling rates of sewage solids also increases their drainability on sand beds and in mechanical filters.

Lime was first used for sewage clarification in England. Then followed various metallic salts added to lime in sewage to precipitate (throw down) suspended matter as a sludge. These metallic salts were mostly of iron (that is, iron sulfates and even iron chloride) or crude commercial mixtures of iron salts and alum; for example, the ABC or Seller's process used alumino-ferric (aluminum sulfate and ferrous salt), blood (from slaughterhouses) and charcoal. Another additive was Ferrozone, which was made by treating Welsh iron ore with concentrated sulfuric acid (an exothermic reaction), allowing it to harden, then crushing it to form a basic ferric sulfate. Then came straight commercial acids (HCl, H_2SO_4) SO_2; phosphoric acid plus lime; and insoluble material like clay, diatomaceous earth (kieselguhr), crushed brown coal (lignite), peat and paper pulp. Some of these materials have become familiar since the advent of vacuum filters. Some of the latter are classed as *filter aids.*

* Presented at 1955 Annual Meeting, Pennsylvania Sewage and Industrial Wastes Assn.; State College, Pa.; Aug. 22–24, 1955.

Sedimentation

In plain sedimentation an attempt is made to hold the dirty liquid relatively still and allow gravity to pull the settleable solids and chemical precipitates down through the water. In the free-settling zone of such settling tanks (that is, where the voids between the wetted solids are largely water) the wetted solids stagger freely downward at various rates determined by their size, shape, density and the laws of free falling bodies. The tank bottom prevents the continued fall so that at some liquid depth the solids start crowding into the void volume sufficiently to interfere with each other's fall. At this transition stage the settling rate decreases. Impeded settling then follows wherein both settling and a crude form of upward liquid filtration occur. As the consolidating wetted solid aggregates settle farther they displace water or clear liquid upward through the existing void channels, thereby materially diminishing the voids volume. The solids and water move in opposed directions, with the water finally doing the staggering upward. When, during the allowed detention period, the voids between the wetted solids diminished to the extent where the flow throttling action of these free channels equals the effect of gravity acting on the solids, gravity can do no more in plain sedimentation.

Sand Bed Draining

Draining on sand beds is a crude form of filtration. Here gravity acts to reverse sedimentation; that is, the solids are held relatively still on a bed of porous sand and some of the clear liquid is permitted to drain through the bed of wetted solids. Ultimately the pronounced jelly-like or spongy resistance of the bed to liquid flow throttles all liquid flow and evaporation takes place, which aids in final dewatering.

In sand bed dewatering and dewatering in mechanical filters some residual water always remains in the capillary voids of the natural spongy cell structure of the sludge solids. The finer the solid particles are the more surface attraction they may have for water. If the solids have a low specific gravity, the wetting effect is increased. Low specific gravity and high surface attraction for water (hydration factor) are characteristic of sewage solids and certain chemical precipitates used to clot or coagulate the fine, wetted gelatinous solids. These are important factors operating in the sedimentation and draining or filtration of all sewage sludges.

Forced Filtration

Forced filtration—that is, mechanical filtration under pump pressure (positive or suction)—came about through efforts to accomplish sludge dewatering in less space and time. With relatively cheap labor the first mechanical filters were batch-operated, pressure filters of the so-called plate or chamber type, adapted from the chemical industries abroad and in the United States. Being of the batch-operating type they used considerable manual labor although they made sludge dewatering independent of the seasons. The various chemicals they used were to render sludge dewatering easier in these cumbersome devices.

In using pressure filters it was discovered that the longer a sludge stood or rested before or during filtering the more difficult it became to filter, or the more chemical it required for forced filtration. Its chemical demand increased with its detention. Fresh sludges were easiest to dewater by pressure filters. However, because fresh sludges were the largest in quantity they required more filter area. Digested sludges were least offensive and of less quantity, but required most chemical. As a rule they were dewatered on sand beds.

When continuous suction filters were first tried on sewage sludges in this

country it was soon found that the digested sludges required more chemical coagulants than did fresh sludges. The so-called "drum filters" were invented in England in 1872 for cement slurries and even for "sewage precipitates" and paper pulp. However, due to the fact the United States was and is essentially a labor-saving country, it was the first nation to develop and perfect these continuous filters in the metallurgical and chemical industries (cyanidation of crushed ores, ore recovery, sugar extraction, etc.) and then sewage sludge dewatering. Oliver continuous vacuum filters were first used in the gold cyanide industry and ultimately in sewage treatment, where they were first used for dewatering waste activated sludge at Milwaukee, Wis. Sulfuric acid was first used for coagulation, then chlorinated copperas, and finally ferric chloride at the Milwaukee plant. The filter cake is dried in rotary ovens and sold as Milorganite fertilizer. In spite of its good fertility value the total filtration costs exceed the value of the fertilizer sold.

Sludge Age and Chemical Demand

The fact that digested sludges require more conditioning chemicals than do the fresh sludges, was discovered to be largely due to the gain in bicarbonate alkalinity during the process of anaerobic digestion. In decomposing the fresh sludge the bacteria convert the putrescible compounds on the one hand to methane and carbon dioxide and on the other to ammonia. The CO_2 and ammonia combine in the sludge liquor to materially increase the alkalinity related to the remaining undigested solids. The digestion process not only reduces the ratio of organic matter to the mineral matter (volatile to ash ratio), but it also increases both the water fraction of the remaining sludge and the amounts of dissolved decomposition products as bicarbonates of ammonium and calcium left in the increasing water fraction.

In other words, the anaerobic bacteria causing sludge digestion, in converting the fresh raw solids to gas and soluble bicarbonates, use the sludge liquor for their own sewer. Instances are known in which the bicarbonates present in the fresh sludges increase some 30 or more times through digestion. Measured in terms of percentage on sludge solids present, an increase of 10 to 20 times is quite common. This alkalinity demand has been conveniently termed the *liquid demand* of a sludge. The remaining demand is conveniently termed the *solids demand* because it depends on the ratio of the volatile matter in any sludge to the inert or mineral matter. As digestion reduces this ratio it automatically reduces the solids demand while greatly increasing the liquid demand.

Elutriation

As the highest liquid demand and the lowest solids demand occur in digested sludges, the simplest method of removing the liquid demand is elutriation. As elutriation is, therefore, purposely used to minimize the sludge alkalinity, an elutriated sludge should be defined as one that has had the alkalinity of its biochemically fouled water reduced by dilution, sedimentation and decantation in water of lower alkalinity. (This definition is more logical than the one found in the "Glossary for Water and Sewage Control Engineering.") (2).

Figure 1 illustrates the distribution steps involved in using single-stage

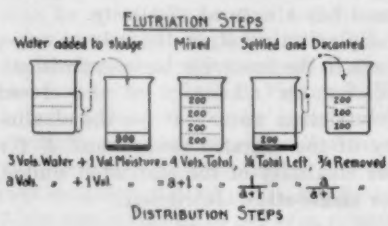

FIGURE 1.—Illustrating distribution of solute during single-stage elutriation.

elutriation with three volumes of pure water to one volume of fouled sludge moisture. Obviously if a volumes of pure water are added to one volume of fouled sludge moisture and mixed there will be $a + 1$ total volumes. Then if the solids are allowed to settle back to a washed sludge equivalent to the original volume and the added volume is poured or syphoned off, the concentration of the original fouling agent left is $\frac{1}{a+1}$. Then if this same dilution, sedimentation and decantation is repeated, the fraction of the original fouling left will be $\frac{1}{(a+1)^2}$, and so on. Using the second wash water decanted for a first new wash and placing the two elutriation tanks in countercurrent series puts the two tanks in so-called countercurrent. Starting with pure wash water, the fraction of original fouling agent left in the final sludge then computes to $\frac{1}{a^2+a+1}$. For example, if four volumes of pure water are used to wash a digested sludge of 3,000-p.p.m. alkalinity, the alkalinity left in the elutriated sludge after countercurrent washing in two tanks computes to $\frac{3{,}000}{4^2+4+1} = 143$ p.p.m., which is remarkably low. Usually, of course, pure water is not available for elutriation so the cheapest source (that is, plant effluent, well water, or even river or lake water) is used. In such a case the computation becomes somewhat more involved because the water used has a natural alkalinity.

Substituting R, or the volume ratio, for a in the foregoing basic expressions, W for the alkalinity of the eluent (elutriating water), D for the alkalinity of the digested sludge, and E for the alkalinity of the elutriated sludge, for single-stage elutriation:

$$E = \frac{D + RW}{R + 1} \qquad (1)$$

It should be remembered that R is really the ratio of the volumes of elutriating water used to the original volume of fouled moisture in the unwashed sludge; that is, the metered ratio of both water and sludge divided by the fraction of water present in the sludge. *For n-stage elutriation*—that is, repeating each wash n times in the same tank or successive tanks at the same ratio R,

$$E = \frac{D + W[(R+1)^n - 1]}{(R+1)^n} \qquad (2)$$

and for *countercurrent elutriation in two mixing and settling tanks*

$$E = \frac{D + (R^2 + R)W}{R^2 + R + 1} \qquad (3)$$

These equations and their reverse are to be found in an earlier publication (3).

So far, the most effective coagulating (or clotting) chemical is ferric chloride, then ferric sulfate, then chlorinated copperas. However, in some cases some ferric chloride can be substituted with cheaper lime. This substitution is of value on heavy fresh sludges, some fairly thin elutriated digested sludges, and unelutriated digested sludges, especially now that the price of ferric salts has climbed to three or four times what it was in 1945. The combination of ferric salts and lime is not used on waste activated or mixtures of waste activated and fresh sludge. On most elutriated sludges ferric chloride, chlorinated copperas, ferric sulfate and combinations of ferric chloride and alum are found to be effective. With elutriated sludges of low alkalinity and high solids, ferric chloride and alum are about the cheapest combination.

Polymer Flocculating Aids

Lately there have appeared on the market new synthetic polymers which result when two or more organic molecules combine among themselves to form a compound of higher molecular weight. Such new polymers can rap-

idly flocculate finely dispersed solids. The first of such polymers to come to the writer's attention is called "Separan 2610," developed by the Dow Chemical Co. of Midland, Mich. The other, termed "Aerofloc," was developed by the American Cyanamid Co. Both when applied to dilute suspensions are effective in producing more rapid flocculation of finely dispersed matter and the floccules not only settle more rapidly but the resulting sludge also filters rapidly and produces drier filter cakes than usual. At present Separan 2610 is the first polymer commercially available in the sewage treatment field and is being evaluated with others at the world's largest digestion and elutriation plant at Hyperion, Los Angeles, Calif. Separan 2610 is relatively expensive, but can be reinforced by small quantities of ferric salts and successfully used in small amounts.

Computing Ferric Chloride Dose

For carefully dosed sludge, free of chemical reducing agents and oil emulsions and a large fraction of fines, the total ferric chloride dose can be computed by the following equation. The *total dose* is expressed in percentage of ferric chloride used on sludge solids. It is made up of the alkalinity or liquid demand, plus the solids demand. That is,

$$\text{Total dose} = \text{liquid demand (p.p.m.)} + \text{solids demand (p.p.m.)} \quad (4)$$

$$\text{Liquid demand} = \frac{H_2O(\%)}{\text{Solids}(\%)} \times \text{p.p.m. alkal.} \times 0.0001 \times 1.08 \quad (5)$$

$$\text{Solids demand} = \frac{\%\text{ vol. (in dried sludge)}}{\%\text{ ash (in dried sludge)}} \times 1.6 \quad (6)$$

Figure 2 is a useful nomograph of Eq. 4. As an example, the dotted line shows a digested primary sludge having 5 per cent solids, 95 per cent water, having an alkalinity of 3,000 p.p.m., and solids having 55 per cent volatile and 45 per cent ash. The liquid or alkalinity demand on the vertical leg, *D*, is 6.15 per cent ferric chloride on sludge solids. Then connecting this demand to the vertical leg on the far right at 55 per cent volatile, the total ferric chloride dose is read at 8.1 per cent on the vertical scale *E*. By elutriating this sludge to 300 p.p.m. and thickening the solids to 8 per cent the alkalinity factor becomes about 0.4 per cent and the remaining solids demand is about 1.9 per cent, making a total dose about 2.3 per cent, which is somewhat more than one-fourth of the unelutriated dose.

Figure 2 also shows that the alkalinity factor or liquid demand in a waste activated sludge can play a definite role. For example, at 500-p.p.m. alkalinity (resulting from storage of the sludge) and 75 per cent volatile matter and a typical thin sludge having 2 per cent solids and 98 per cent water holding this alkalinity, the liquid demand alone is almost 2.7 per cent ferric chloride on solids, and the solids demand computes to an additional 4.8 per cent, making a total dose of 7.5 per cent ferric chloride. Thickening such a sludge may result in producing 5 per cent solids and an alkalinity of 800 p.p.m., which will reduce the liquid demand to about 1.64 per cent and leave the solids demand about 4.8 per cent, making a total dose of about 5.4 per cent, which is considerably better than the 7.5 per cent total resulting with the thinner but fresher sludge of lower alkalinity.

Digesting a waste activated sludge may be good for gas production and power generation, but without the benefits of elutriation the chemical demand can become quite large. For example, in using ferric chloride alone, on a digested mixture of waste activated and primary sludges having 97 per cent moisture of 3,000-p.p.m. alkalinity, 3 per cent solids of 60 per cent volatile matter, the liquid demand is 10.5 per cent and the solids demand another 2.5

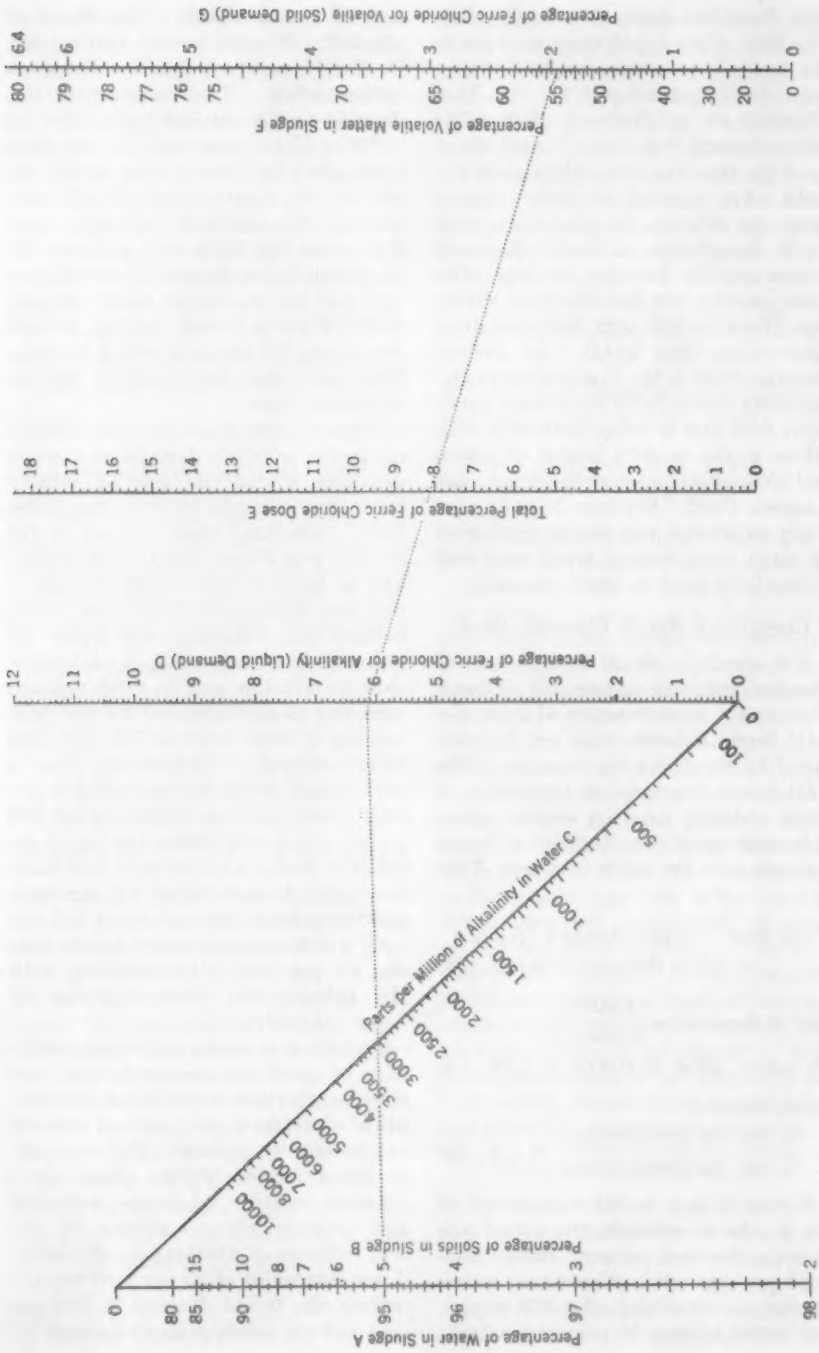
Percentage of Water in Sludge A
Percentage of Solids in Sludge B
Parts Per Million of Alkalinity in Water C
Percentage of Ferric Chloride for Alkalinity (Liquid Demand) D
Total Percentage of Ferric Chloride Dose E
Percentage of Volatile Matter in Sludge F
Percentage of Ferric Chloride for Volatile (Solid Demand) G

FIGURE 2.—Nomograph for computation of sludge dosing in accordance with Eq. 4.

per cent which makes a total of about 13 per cent. It would be too expensive to use ferric chloride alone on such a digested sludge. Therefore, without the benefits of elutriation a combination of ferric chloride and lime can be employed (for example, about 5 or 6 per cent ferric chloride and 15 per cent lime, which in total cost amounts to about 7.3 per cent of ferric chloride alone, when the cost of lime is $15 per ton and ferric chloride costs about $100 per anhydrous ton).

Improving Cake Yield

Intermediate Elutriation

With elutriation of digested mixtures of primary and waste activated sludges the elutriated product may persist in remaining thin, which sometimes results in low cake yields even at low ferric chloride doses. There are several causes of this phenomenon and several cures. The first cure is intermediate elutriation (4) (5) (that is, single-stage elutriation between the active heated stages of digestion and the inactive unheated secondary or storage stage of digestion). This is a recent elutriation development (6) as used at San Francisco and Wilmington, Baden-Baden and other places in Germany, and tried by Torpey and Lang (5) in New York's Jamaica Bay plant, principally for increasing the percentage of solids in the secondary stored sludge for barging to sea. This increases the alkalinity of the stored secondary sludge, but this can readily be removed by final elutriation.

Interstage elutriation is used in Germany for concentrating sludge prior to dewatering of the digested material on sand beds. For example, at Baden-Baden the first-stage digested material containing about 9 per cent solids is washed before second-stage storage and again after same, which raises the solids to 20 to 22 per cent. It is then dewatered on the sand beds in about 14 days. The beds are filled to a depth of 12 in.

Thermophilic Digestion

The second cure is the use of thermophilic digestion (120° F.), which according to Garber (7) when combined with elutriation produces good filter yields at low ferric doses. Thermophilic digestion with interstage elutriation and followed by countercurrent elutriation should produce further improvements.

Ferric Chloride and Lime

The third cure is the use of a small amount of ferric chloride followed by a small percentage of lime on elutriated digested mixtures of waste activated and primary sludges or on certain digested sludges containing some industrial wastes. Where the digested material contains a lot of fines which settle to a rather thin sludge (5 or 6 per cent solids) and result in a cake of high compressibility, this combination can produce excellent results. Before initiating the use of thermophilic digestion at the world's largest digestion plant, Hyperion in Los Angeles, this combination was quite effective, but was abandoned because the dried fertilizer became alkaline. The natural alkalinity of the soil prevalent in Southern California could not tolerate an alkaline fertilizer. At the Cleveland Southerly plant the digested mixture of waste activated and primary sludges is elutriated and dosed with ferric chloride and lime. The filter cake is incinerated. This plant uses about one-half the chemicals it did before elutriation was installed.

The bar graphs of Figure 3 show where ferric chloride (or the cost-equivalent of ferric chloride and lime) goes for the various types of sludges collected from domestic sewage only and dosed and dewatered in continuous vacuum filters. Here the ferric chloride distribution for the liquid and solids demands are shown per 1,000 persons daily. In calculating the pounds of digested solids, there has been assumed in all cases a reduction

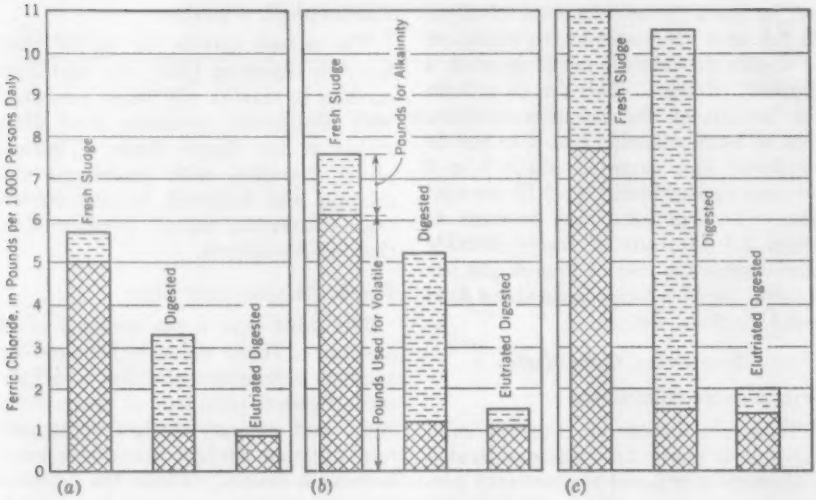

FIGURE 3.—Quantity of ferric chloride required for vacuum filtration of various domestic sludges.

of 65 per cent of the fresh solid volatile in digestion, and 66 per cent in digestion followed by elutriation, as the latter process removes some volatile while further concentrating the sludge. There is always a loss of some solids through supernatant withdrawals, elutriation and vacuum filtration.

Figure 3, taken from a previous paper (3), supplies illuminating evidence of where ferric chloride and its equivalent coagulants go for the various types of sludges. In this chart, (a) represents sludge from plain sedimentation plants equipped with digestion handling domestic sewage, (b) represents sludges from trickling filter plants equipped with sedimentation and digestion, and (c) represents typical complete treatment having sludge activation, sedimentation and heated sludge digestion.

In all fresh sludges the solids demand (cross-hatched portion) is relatively high, while the liquid demand is relatively low. The reverse is the case with straight digested sludges (unelutriated) where, notwithstanding good mineralization and volatile matter reduction, and lowered volatile-to-ash ratio, the high percentage of alkalinity and its associated moisture makes this factor greatly predominant in coagulant demand. The lowest total demand in all cases comes where the solids demand has been reduced through mineralization by digestion and the liquid demand has been mostly removed by elutriation.

The graph of sludge (c) certainly indicates there is little if anything gained in using vacuum filters on thin digested mixed primary and waste activated sludges without the benefits of elutriation, or thermophilic digestion with interstage elutriation and final elutriation. If vacuum filters are not to be used, it is better engineering to provide digestion with interstage elutriation and sand bed filtration.

Dosing Equipment and the Vacuum Filter

In 1941 the author (1) listed about two dozen various factors involved in the construction, installation and operation of the continuous vacuum filter itself, including the accessory equip-

ment, with about seven additional factors relating to the vacuum filtration of various types of sewage sludges (that is, the nature of sludge solids, amount of biochemical products in the sludge moisture, kinds of coagulants used, mixing of sludge and coagulant before feeding the dosed mixture to the vacuum filter and during filtration of said mix, kind of floc produced, amount of cake scouring and sloughing during drum rotation and agitator movement, pH of filtrate, and relative viscosity of the dosed sludge).

Considerable attention was paid to the pre-mixing of sludge and coagulant and feeding of the conditioned mix into the filter. The fact has long been emphasized that:

1. Conditioning mixing equipment is usually designed and built entirely too large. This is primarily the fault of the filter manufacturers.

2. Feeding conditioned sludge from the conditioning mixer to the filter pan through inverted feed piping is quite wrong. This practice causes definite traffic jams of flocced sludge in the inverted pipe and makes the detention of the flocced sludge too long. This can only result in depletion of the floc.

3. Constantly agitating the conditioned sludge in the filter while the drum is rotating is detrimental, especially at a high drum submergence. This latter item should be numbered factor 4, as high drum submergence is quite erroneous.

The simplest dosing equipment was employed at Annapolis, Md. (8)(9), some years ago on the elutriated digested sludge (see Figure 4). Here the small stream of weak ferric salts is jetted through the side of the mixing tank (nothing but a converted oil drum) into the stream of heavy elutriated sludge as it flows into this tank on its way out through a baffled overflow at the bottom. This results in thorough, rapid mixing of sludge and chemical.

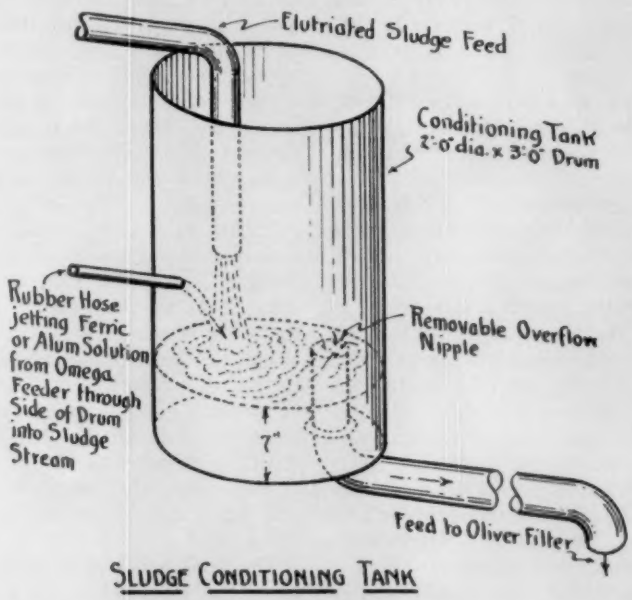
Elutriated Sludge Feed
Conditioning Tank
2'-0" dia. x 3'-0" Drum
Rubber Hose jetting Ferric or Alum Solution from Omega Feeder through Side of Drum into Sludge Stream
Removable Overflow Nipple
7"
Feed to Oliver Filter
SLUDGE CONDITIONING TANK

FIGURE 4.—Simple but effective sludge conditioning tank constructed from a 50-gal. oil drum.

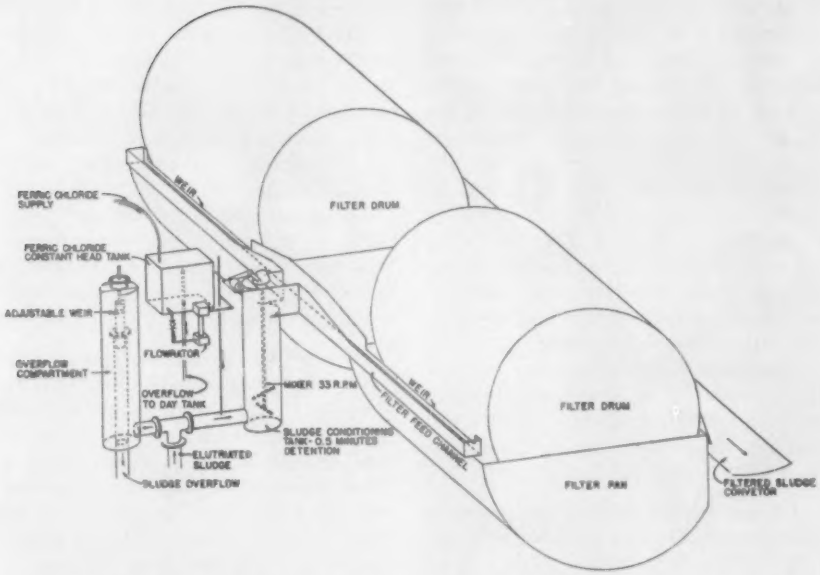

FIGURE 5.—Schematic filter feed arrangement for Sacramento sewage treatment plant.

The well-flocculated sludge overflows the removable overflow nipple in the drum bottom and flows directly into the top of the filter pan. There is no inverted piping.

This idea was refined and excellently adapted to a larger filter installation for the new treatment plant at Sacramento, Calif. (Figure 5). This plant has two large vacuum filters * dewatering elutriated digested sludge. The sludge is elevated through a vertical riser, joined on one side to an adjustable telescopic overflow weir, while on the right the sludge flows up through an 18-in. inside diameter pipe in which a slowly rotating vertical shaft with staggered mixing paddles revolves. Note that only undosed sludge overflows the adjustable telescopic overflow. Dilute ferric solution enters the mixing well at the bottom, through an adjustable "flowrator," mixes thoroughly with the upward flowing sludge, then the conditioned sludge overflows the small conditioning vertical chamber into an open feed channel located along the rear top side of both filter units and overflows the top of the filter pans into same against the upward revolving drums, under the shower header located on the rear of each drum. One vertical mixer or conditioner is located between the two large filters, the arrangement rendering the inflowing floc easily visible at all times so that its well-flocced condition can be readily viewed. The sludge is easily diverted to either or both of the two filters by inserting or removing stopgates at the feed end of either of the two feed channels. At the end of a filter run the sludge pump or elevator is simply stopped and the filter or filters allowed to suck down until the submergence is low, drained, and the sludge left in the feed piping and mixer simply drained back to the sludge well.

The author has thoroughly emphasized the importance of avoiding a high submergence of a vacuum filter drum, especially when handling well-

* Oliver-United.

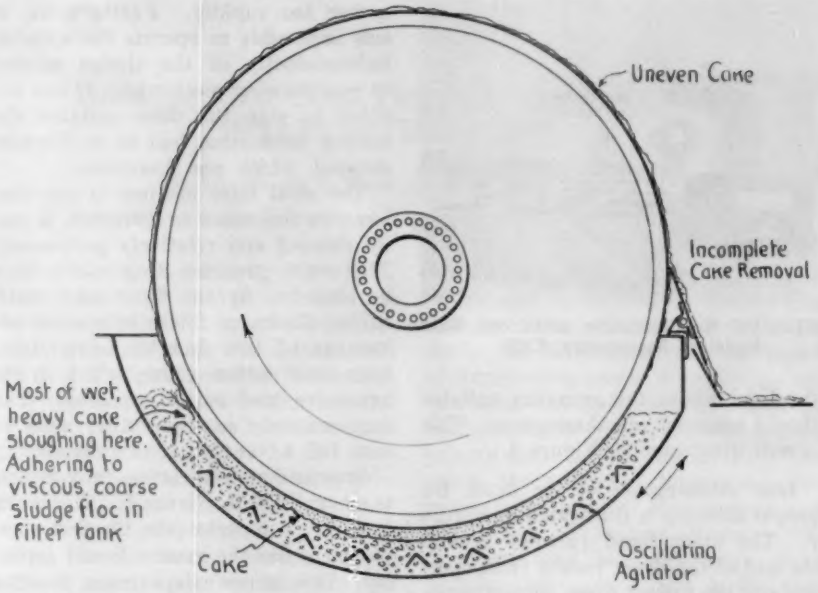
Uneven Cake
Incomplete Cake Removal
Most of wet, heavy cake sloughing here. Adhering to viscous coarse sludge floc in filter tank
Cake
Oscillating Agitator

FIGURE 6.—Results of too great submergence of filter drum in heavy sludge floc.

flocculated sludges. It is important to do two things, as follows:

1. Operate the filter agitator only one or two minutes every hour or half hour. This means that it should be automatically operated by a timing switch.

2. Avoid a drum submergence above

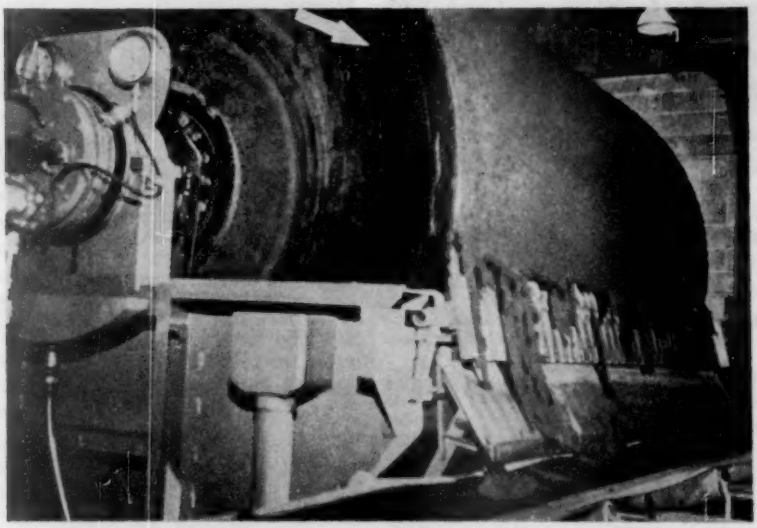

FIGURE 7.—Filter cake discharging from a 300 sq. ft. filter. Note black submergence band (arrow).

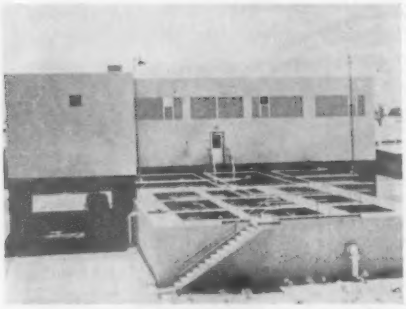

FIGURE 8.—Elutriation tanks and filter building, Sacramento, Calif.

the level where the swinging agitator should come out of submergence. This is well illustrated in Figure 6.

Low submergence of the drum for proper filtering is illustrated in Figure 7. The black band (arrow) around the end of the drum results from operating at the proper drum submergence.

In February 1955, the author serviced a new elutriation installation equipped with a so-called "package unit vacuum filter." In this case the speed of the agitator could not be varied or the agitator intermittently operated. In addition, it ran altogether too rapidly. Furthermore, it was impossible to operate the agitator independently of the sludge mixing or conditioning mechanism; if one decided to stop the filter agitator the mixing mechanism had to be likewise stopped, which was disastrous.

The ideal filter medium is one that has zero resistance to filtration, is easily cleaned and relatively permanent. The entire pressure drop would then be absorbed by the filter cake itself. String discharge filters take some advantage of this fact by using light, open-mesh cotton gauze, which is inexpensive and easily replaced. The comparatively new coil filter aims to take full advantage of this theory.

Intermediate elutriation tank design is exemplified in Figure 8. The tanks have two compartments, the first compartment has the greater liquid capacity. This larger compartment handles all liquid products from the heated, first-stage digesters which can be pumped to secondary storage for further solids concentration. The concentrated sludge is then rewashed in the smaller elutriation compartment and filtered.

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DESIGN AND CONSTRUCTION OF A LARGE INTERCEPTING SEWER *

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The Westchester County, New York, Department of Public Works has under construction a new shoreline sanitary intercepting sewer located in the city of New Rochelle. This paper is presented to illustrate the unusual variety of design and construction problems encountered.

The project includes two submarine inverted siphon crossings, two new rock tunnels with revisions to an existing tunnel, concrete inverts in the tunnels, pipe on pile and concrete pier foundations, pipe laid through tidal mud flats, and pipe located in existing trenches through rock.

History

In 1946, the city of New Rochelle, under order from the Interstate Sanitation Commission and the New York State Department of Health to reduce pollution of waters in the area, entered into a program designed to remedy existing conditions. A consulting engineering firm was engaged to submit a report, prepare the necessary plans and specifications, and make an estimate of costs. Upon completion, it became evident that the financing of such a project would severely tax New Rochelle's legal borrowing power, thereby seriously curtailing other needed civic improvements. In late 1949, the New Rochelle City Council requested the county of Westchester to investigate the situation and determine whether a new county sewer district could be created to finance and undertake the work. After some study, the Westchester County Board of Supervisors passed a resolution authorizing the formation of the New Rochelle Sanitary Sewer District, comprising most of the city of New Rochelle, the village of Larchmont, and parts of the town of Mamaroneck and the village of Pelham Manor. The necessary bond issue was approved by popular county-wide vote in the election of November, 1950.

Existing Collection Facilities

The interceptor system then in service was built in 1926 and included two pumping stations with force mains and gravity sewers. Sewage was conveyed to a point in Hudson Park, New Rochelle, opposite the existing City Yard sewage treatment plant, and was carried under the harbor by a single 30-in. cast-iron pipe inverted siphon. Emergency overflow facilities existed at three points of interception. In storms of even moderate intensity these lines functioned to relieve some of the excess combined flows. However, flooding of streets and basements was caused by a lack of sufficient capacity to handle excessive infiltration and surface waters illegally introduced into the contributing sewers. Flow gaugings taken at the City Yard plant indicated peak wet weather flows at least three times the average dry weather flows, despite the inability of collecting sewers to carry all of their wet weather flow without overflowing.

* Presented at 1956 Annual Meeting, New York Sewage and Industrial Wastes Assn.; New York, N. Y.; Jan. 18–20, 1956.

Basic Design Data

A new primary-type sewage treatment plant has been built in New Rochelle and is in operation (1). Sewage is being received from three new intercepting sewers, entering the plant from the north, east and west. The west, or shoreline interceptor, is the topic under consideration.

The West Intercepting sewer is about three miles long and will, upon completion, collect sewage from the entire westerly portion of the city of New Rochelle and part of the village of Pelham Manor. Six separate drainage areas are served, with a combined tributary area of 1,800 acres and a 1950 population of 32,000 persons.

Because of the difficulty and cost involved in the enlarging of intercepting sewers, a 50-year design period was used. It was decided, for economic reasons, that some portion of peak wet weather combined flows would have to be released through emergency overflows, after chlorination.

Location

Two general locations were taken into consideration for the West Intercepting sewer. The first, along the north shore of New Rochelle harbor, was used in the design prepared in 1947, prior to the formation of the county sewer district. Subsequent construction, including apartment houses, a school, and a large oil storage depot, plus evidence of considerable rock along the proposed line, made the selection of another route desirable. An alternate location through low lying ground along the south shore of New Rochelle Harbor was taken into consideration. It was apparent that the amount of underwater work would be increased and that pipe foundation problems would exist. However, rock excavation would be greatly reduced and the disruption of traffic and damage to private property would be minimized. The city of New Rochelle advised that proposed land developments would be better served by this second route. For these reasons, the location along the south shore of New Rochelle Harbor, on Davenport Neck, was selected.

Design Population and Flows

The area contributary to the West Intercepting sewer is for the most part residential in character. Much of the land has been held in past years as one-family estates. In recent years, a trend has developed towards the breaking up of these large parcels into single-unit housing developments and multiple-unit apartment houses. The area also contains several beaches, including the county park at Glen Island and the New York Athletic Club, which attract large groups of people from outside the district during the summer months. These factors were taken into consideration in estimating future population densities and design flows.

Using information obtained from house-to-house population counts and various governmental agencies, and assuming a curvilinear rate of growth, a design population of 40,000 was arrived at for the year 2000. This gives a density of approximately 22 persons per acre.

Per capita sewage flows for the design period were based on studies made of water consumption and gaugings of dry and wet weather sewage flows.

Average dry weather daily per capita flows were established at 113 gal. for sewage and 44 gal. for normal infiltration. Sewer design was based on a maximum wet weather flow of 390 gal. per capita per day plus an additional factor of 25 per cent in anticipation of high seasonal flows and to reduce, as much as possible, the discharge of combined storm sewage to waters used for bathing purposes. Maximum design flow is 430 per cent of average dry weather flow.

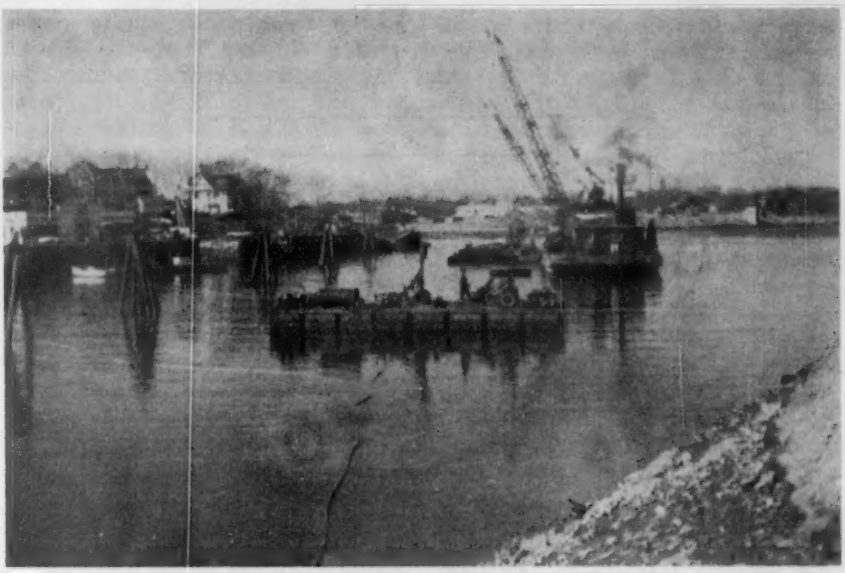

FIGURE 1.—Drilling rig working ahead of flotation and excavating outfit. Pile clusters aid in mooring working equipment in exact location.

Echo Bay Inverted Siphon

The submarine crossing under Echo Bay Harbor from Hudson Park, New Rochelle, to the sewage treatment plant was made with a twin-barrel inverted siphon 1,400 ft. long. The peak design flow of 20 m.g.d. is carried by 24-in. and 30-in. pipelines. The velocity at average flow is 3.5 ft. per sec. Sewage is brought to an inlet diversion chamber at elevation − 4.75, is depressed under the harbor to a dewatering chamber at elevation − 18.0, then rises up to an elevation of − 7.5 at a flow measuring chamber. Parshall flume readings are transmitted to the control building of the treatment plant, where they are indicated and recorded. All interceptor flows are measured separately before reaching the plant, allowing a close check on any sudden change in total plant flow.

A weir and slide gate arrangement in the diversion chamber directs average weather flows through the 24-in. line and peak flows through both lines. Either barrel can be cut out of service and dewatered to the chamber provided. Slopes are such as to prevent any possible trapping of air or gas in the lines.

The underwater elevation of the siphons was fixed below the minimum clearance line established by the War Department for pipelines crossing federal channels. Subaqueous soundings, probings, and borings were taken along the proposed line (Figure 1). The soundings revealed a shallow body of water, varying in depth from 17 ft. at average high tide to 3 ft. at average low tide. The probings and wash borings indicated a bottom consisting of ledge rock overburdened with layers of silt, sand and gravel containing pockets of blue clay and covered with a thick blanket of mud. Three different foundation conditions developed which were treated as follows:

1. In suitable material such as sand, gravel, or rock at subgrade, the pipes were laid on pre-cast concrete sills at 16-ft. centers. A cushion, of at least

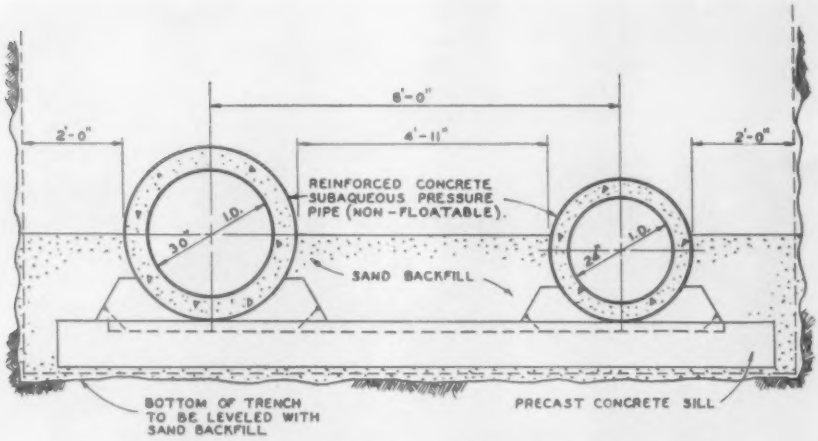

FIGURE 2.—Bedding of pipe laid underwater in rock excavation.

8 in. of sand, was used below the sills in rock (Figure 2).

2. When a shallow layer of unsuitable material existed at subgrade, two methods of construction were made available. Pile bents at 16-ft. centers could be used where rock was at a sufficient depth to allow adequate lateral support. Where rock lay close to subgrade the unsatisfactory material was excavated and replaced with sand fill. Pre-cast concrete sills, as in condition 1, were then used.

3. Where a deep layer of unsatisfactory material occurred at subgrade, pile supports were called for. Pile bents at 16-ft. centers were used (Figure 3).

Subaqueous-type reinforced concrete pipe with rubber and steel joints was specified for the work. The pipe was supplied in 32-ft. lengths to reduce the number of underwater joints and to keep infiltration to a minimum. Pipe thicknesses were such as to allow the dewatering of either line for cleaning without danger of floating.

Construction was begun in February, 1955. All private boat anchors and moorings in the area were moved to temporary locations for the duration of the contract. As the shallow

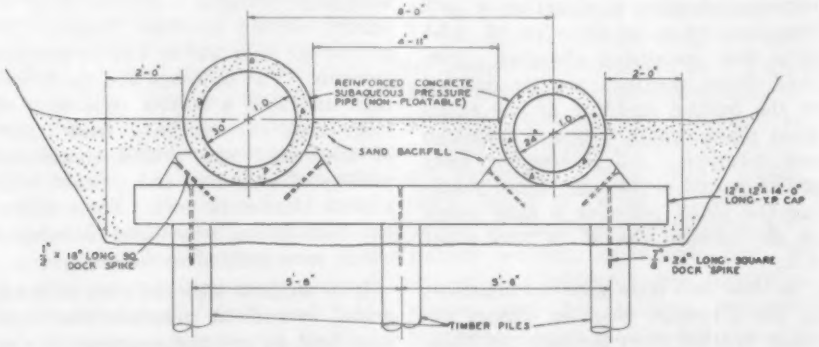

FIGURE 3.—Detail of three-pile bent for underwater construction.

nature of the harbor would restrict work to periods of high tide, a flotation channel 80 ft. wide, with a minimum draft of 8 ft. at low tide, was excavated along the line of the work and out to deeper waters. This permitted work to be carried on at all tides and allowed enough room for equipment to move freely. All excavated material was loaded on barges and towed to dumping grounds at sea.

Pile clusters were then driven at 100-ft. intervals on a line 60 ft. off and parallel to the center line. The clusters were used for mooring equipment and operation barges which would be in position to lower pipe over the side on either line.

Trench excavation was then carried to grade and projecting rock surfaces were stripped for measurement prior to removal. The 24- and 30-in. siphon lines are spaced at 8 ft. center-to-center to allow the necessary minimum clearance of 5 ft. between the pipes for the marine diver's operations. A clearance of 2 ft. between the pipes and the side trench walls was called for, giving a trench about 15 ft. wide at subgrade. Drilling and blasting operations were begun in the rock areas and piles were driven where required. It is interesting to note that before any underwater blasting was done, warning was given to all beaches in the vicinity to clear the water of bathers. This was done to prevent any possible injury to swimmers from underwater concussions.

All work connected with the preparation of foundations, the setting of concrete sills, the grading of sand fill, the cutting off and capping of piles, and the laying of pipes was done by, or under the direction of, marine divers. Constant two-way communication was kept between surface barges and the underwater workmen.

Measurements for grade were taken from the prevailing water level, which was constantly checked with tide gauges mounted on the pile clusters. Grades were transmitted under water using a graduated iron pipe, lowered from a raft anchored alongside the pipe laying barge. The raft was located over the centerline of either pipe, at a known station. Line and station were carried along as the work progressed using sight ranges and by chaining, and were checked by transit from land. The first few transit checks revealed that the contractor was obtaining an amazing degree of accuracy using methods based on wide experience in marine work, and without benefit of instruments. The importance of such experience cannot be overemphasized in this type of highly specialized work.

Pipe was lowered into position (Figure 4) supported by two cable slings connected to the main rig cable by a universal connection. Timber pipe chocks were tied to each pipe section, to be anchored to the concrete sills or pile bents as a protection against rolling or lateral movement of the lines. To facilitate pipe laying operations, and to prevent any possible divergence from line, pipe in one line was laid two pipe lengths in advance of that in the other. Pipe in the second line was then set by using a timber cut to equal the clear distance between the two lines. This method proved to be satisfactory as well as practical, since the divers work by touch in near zero visibility.

Pipe was laid from the land chambers to the middle of the harbor. Before closure, both siphon sections were tested for leakage by an internal hydrostatic head of 20 ft. of water above tide level at the time of the test. A total leakage of less than 1.5 g.p.m. was allowed for the entire job. This was equivalent to about 147 g.p.d. per inch diameter per mile. Actual leakage was within this limit.

The final closures were made in August, 1955, using special pieces fitted to field measurements. The actual closures were within 3 in. of the theoreti-

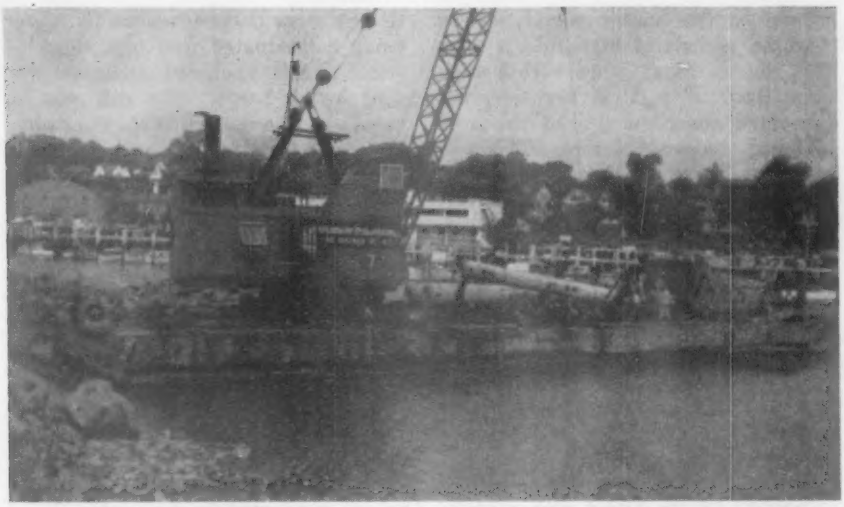

FIGURE 4.—Laying 32-ft. lengths of 30-in. reinforced concrete pipe from barge rig.

cal lengths. Following the closures both lines were drained to the dewatering chamber and infiltration was measured at high tide. The same standards specified for leakage were used and met.

Sand backfill was then carried to the centerline of the pipes, care being taken to deposit the sand evenly so that no unbalanced loads would be placed on the lines. Sand was moved to its final position by the divers using pressure hose jets. No further backfilling was done in the flotation channel or pipe trench, as it was felt that natural mud movements would soon completely cover the pipes.

The work was done in seven months by the contracting firm of Spearin, Preston and Burrows, New York, N. Y., at a final contract cost of $420,000.

Hudson Park Tunnel

The second phase of construction was begun in April 1955. This was fundamentally a land job embracing 900 ft. of rock tunnel and about 5,600 ft. of 42-in. reinforced concrete pipe sewer. The tunnel work will be described first.

Preliminary investigations had revealed an existing 400-ft. long rock tunnel driven in 1903 under Hudson Park for a now unused offshore outfall sewer. The tunnel was unlined, roughly 8 ft. square in section and contained the abandoned 24-in. cast iron pipe outfall line.

The grade of the tunnel closely matched that of the proposed work and could be used intact by removing about 2 ft. of rock from the bottom for a distance of 200 ft. An expert was brought in to examine the tunnel and give his opinion on the feasibility of such alterations. The report was favorable, and was based on the existence of a hard granite in the area and the absence of any notable rock falls in the tunnel during the past 50 years.

Work was begun on two unlined rock tunnels branching off from the existing tunnel and required to connect the diversion chamber at the entrance to the Echo Bay siphon with the sewer on Davenport Neck. A tunnel section 5½ ft. wide by 6 ft. high was used. Access to the work was gained by reopening the shaft used in the original construction. The 500 ft. of

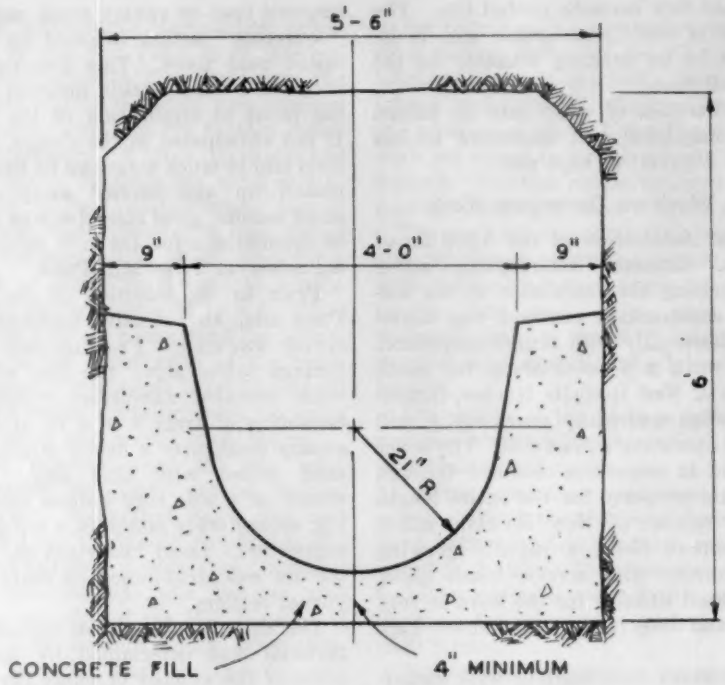

FIGURE 5.—Paved invert used in rock tunnel construction.

new tunnel and the necessary revisions to the existing tunnel were completed without incident in four months. It is of interest to note that no appreciable damage was done to several large structures, including a park department greenhouse, located directly above the tunnels. However, work was temporarily halted on several occasions to permit band concerts to be held in an outdoor auditorium located next to the main shaft. Rock excavated from the tunnels was stockpiled for future use as foundation material, where required, on other parts of the job.

Favorable rock conditions and economy suggested the use of concrete inverts in the tunnel instead of pipe (Figure 5). The invert was poured using welded steel forms supported on small concrete piers, shaped to fit the invert bottom. The individual forms were 8 ft. long and the invert was poured in 64-ft. sections, concrete being placed on one side of the form and vibrated until it appeared on the other side. Concrete was brought to the job by truck, mixed at the site and deposited in a hopper above ground, from where it was pumped into the tunnel. The 6-in. pump discharge line was supported in the tunnel independently of the formwork to avoid jarring of freshly placed concrete.

Forms were stripped for re-use the following day with no injury to concrete surfaces. Some decomposed rock was encountered which became soft and spalled off on contact with air. To prevent rock falls in the sewer, these areas were lined with wire mesh and covered with a 2-in. layer of gunite. To allow for its future use as an emergency outfall, a valved connection was made from the new interceptor to

the old New Rochelle outfall line. The valve is readily accessible and is located in an existing manhole on the outfall line.

Infiltration of water into the tunnel was negligible and amounted to less than 3 g.p.m. at high tide.

Work on Davenport Neck

The installation of the 5,600 ft. of 42-in. diameter intercepting sewer comprising the remainder of the second construction contract was begun simultaneously with tunnel operations. The work is located along the south shore of New Rochelle Harbor, including what was many years ago a mill pond operating a grist mill. The sewer is laid in easements obtained through private property for the entire length of a section of New Rochelle called Davenport Neck, a rapidly growing community with several beach clubs. The land suitable for the work is very low and only a few feet above high tide.

To avoid complications with numerous property owners, and to take advantage of the absence of rock excavation, the sewer was located along the edge of Titus Mill Pond, just outside of the shoreline property limits, for a distance of about 1,500 ft. However, some of the advantages of this location were offset by the existence of high ground water and unstable foundation conditions.

Communities throughout the shore the repeated failure of pipelines located in low lying land. These locations were originally selected for economic reasons and in many cases no special attention was given to pipe foundations. As community growth and filling operations encroached on these swampy areas, pipe failures increased. Only a few years ago, a section of the New Rochelle sewage force main crossing Titus Mill Pond was moved more than 16 ft. by a fill placed for the construction of a new apartment house. Any appreciable superimposed load on swamp muck causes a "squeezing" action followed by a so-called mud wave. This heaving can occur at a considerable distance from the point of application of the load. If not anticipated in the design, pipelines laid in muck areas can be literally picked up and carried away. For these reasons, close attention was given to foundations for the new intercepting sewer in Titus Mill Pond.

Prior to the selection of the Mill Pond site, an intensive underground survey was made. Probings and wash borings taken along the line of the work revealed subsurface conditions consisting of from 4 to 6 ft. of black swamp muck over a firmer stratum of sand mixed with blue clay. This rested on a soft rock bottom containing, among other minerals, a low-grade copper ore. Local historians say that the ore was strip-mined by early Huguenot settlers.

The elevation of suitable foundation material was determined by studies made of the number of blows per foot required to drive the wash boring casing, and was confirmed by samples taken at various levels. Wherever possible, the line of the sewer was established so as to insure proper pipe bedding in firm foundation material. It was realized that suitable foundation conditions would not exist along the entire line of the work. In anticipation of this, special methods of construction were made available to the contractor. If the distance to suitable foundation was not considered excessive, excavation was to be carried below grade and backfill made using selected material. If suitable foundation material was found to be more than 6 ft. below subgrade, pile supports were specified. It later developed that this condition did not exist in the work and piling was not used. Although not anticipated in the original design, one section of pipeline, about 180 ft. in length, was supported by the use of concrete piers.

The contractor's construction procedure in the Mill Pond is of interest. An existing earth dam located at the western end of the pond was repaired and used to prevent the further influx of tidal waters. A large pump was put into service to drain the pond and to handle leakage and surface runoff. Fill was then brought in and placed over the center line of the pipe for a width of about 20 ft. and to a compacted depth of from 4 to 5 ft. This was used as an access road for equipment in the prosecution of the work. Excavation was made through this fill with a crane equipped with an extra long boom and a clam shell bucket.

The removed road fill was piled separately for later use as backfill material. Excavated muck was cast as far from the trench as possible and spread out over a wide area. Excavation was carried from the sea wall along the edge of the Mill Pond to at least 6 ft. outside of the sewer line. Soft material was removed to solid foundation and replaced with selected material to within 8 in. of the bottom of the pipe. A crushed stone foundation for the pipe was then placed and compacted. Pumps were put in operation to dewater the trench ahead of pipe laying and to keep it dewatered. The pipe was laid and selected backfill was placed to a level 12 in. above the top of the pipe for the entire width of the trench. Excavated swamp material was then replaced over the pipe to original grade.

As previously mentioned, it was found necessary to use concrete piers to support and anchor the pipeline for a distance of about 180 ft. The section in question passes through a heavy miscellaneous fill about 10 ft. in depth, laid on swamp muck. At first it was decided to remove the muck to firm bottom and lay the pipe on a crushed stone fill varying from 4 to 6 ft. in depth. This method was used for a distance of about 60 ft., when movement was noticed in the fill adjacent to the trench. This movement, caused by a sliding action of the fill on the lubricated muck surface, caused a lateral and vertical displacement in the pipeline of about 2 ft. Conditions were not suited to the use of pile foundations. For this reason concrete supporting piers were used (Figure 6).

The piers are spaced at 16-ft. centers and reinforced concrete pressure pipe with rubber and steel joints in 16-ft. lengths was used. The pipe was strapped down to the piers using galvanized wire rope tightened by turnbuckles.

The design of the piers is based on possible horizontal and vertical loadings transmitted to the pipe and piers by filling operations and mud wave action. Wood sheeting was driven to hard bottom and excavation was carried 2 ft. farther. The piers were sized to allow adequate room inside of the sheeting for excavation with a clamshell bucket.

Reinforced concrete tongue-and-groove pipe in 8-ft. lengths with rubber gasket joints was specified for the remainder of the work. The so-called "diaper joint" was used as a further precaution against infiltration. A heavy piece of cotton fabric about 7 in. wide, with wires along the edges, is placed around the pipe at the joint. A 1 : 2 mixture of mortar is introduced at the top and worked around the pipe. Using this method, proper mortar caulking is assured around the bottom of the pipe, which otherwise is always questionable. Interior joints were caulked with mortar by hand.

Special attention was given to manhole construction, as it is frequently a source of trouble. Manholes were constructed almost entirely of concrete, using a poured concrete base with a pre-cast barrel. The base was box shaped and was carried to a point 1 ft. above the top of the sewer. The general arrangement of the lower poured section varied, in that the sides through which pipes enter and leave

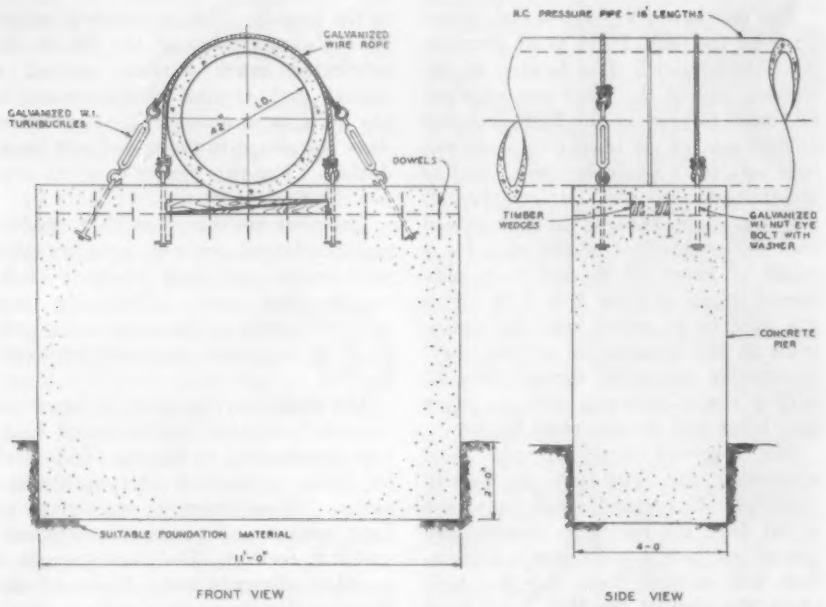

FIGURE 6.—Concrete pipe supports used in fill on muck under-layer.

the manhole were always kept normal to the pipe center lines. Cast iron manhole steps are cast into the pre-cast barrel and the top manhole piece is a truncated cone section, vertical on one side. This allows a vertical run for manhole steps. Special galvanized steel wall sleeves were cast into the concrete bases and the pipe joints at the manhole were made using rubber gaskets protected with a poured bituminous joint. Short lengths of sewer pipe, in 1-ft. increments, were specified, eliminating the need for cutting off random pipe lengths at manholes. This method of construction has proven very satisfactory. Sealed manhole covers are used in all locations below extreme high tide level. Allowable leakage and infiltration requirements were 150 g.p.d. per mile per inch of pipe diameter. Leakage tests are made with the pipes full and under a head of 5 ft. of water above the prevailing ground water level. When ground water is 5 ft. or more above the top of the pipe, a measurement of infiltration is made. Portions of the sewer line already tested have met these requirements.

This second phase of construction is nearing completion and is in partial operation. The work is being done by the contracting firm of William Casey and Sons, Inc., Garden City Park, N. Y., at a contract price of $480,000.

Completion of West Intercepting Sewer

The remainder of the work to be done to complete the West Intercepting sewer has for the most part been designed and is scheduled for construction in the near future. Many of the design and construction features already mentioned will apply to this work and therefore are only briefly described.

The last phase of the work will include a 700-ft. twin-barrel inverted siphon under New Rochelle Creek, 1,600 ft. of 42-in. sewer on land lead-

ing to the existing Whitewood Avenue pumping station, 2,250 ft. of 24- and 36-in. pipe up Whitewood Avenue to Mount Tom Road, and about 2,100 ft. of 18-in. pipe to the village of Pelham Manor, with one emergency overflow chamber at the foot of Whitewood Avenue.

One design feature of the contemplated work in Whitewood Avenue is worthy of mention. An existing 24-in. cast iron pipe is now in service and carries sewage from Mt. Tom Road to Whitewood Avenue, a distance of 1,300 ft. The entire line is laid through rock in a private golf course. It is intended to install a relief sewer directly above and in the same trench as the 24-in. sewer without disturbing or removing the existing facilities. The present flow of sewage will, therefore, be maintained; expensive pumping operations during construction will be eliminated, and a considerable saving in rock excavation will be realized.

This method of construction has been used with success by Westchester County in the town of Mamaroneck and has previously been presented for publication (2).

The completion of work on the West Intercepting sewer is scheduled for early 1957, at which time a long-standing problem will have been finally resolved.

References

1. Griffin, G., and Brown, J. M., "Westchester County Solves Some Sewerage Problems." THIS JOURNAL, **28**, 1, 18 (Jan., 1956).

2. Marcon, W. A., "Over-Under Relief Sewer Design Simplifies Construction." *Water and Sewage Works*, **102**, 226 (1955).

CORRECTION

In the paper on "Biological Purification of Citrus Wastes," by James B. Lackey, Wilson T. Calaway, and George B. Morgan (THIS JOURNAL, **28**, 4, 538 (Apr., 1956)), an error occurs in the first paragraph on page 538. The eighth line, which reads "the volume of fruit treated are certain," is incorrect. The line should read: "chain carbon compounds and contain." The entire paragraph, in its correct form, is as follows:

"Almost any organic compound is susceptible to attack by some living organism. Those organic mixtures which are attacked by the greatest variety of organisms are usually readily soluble, are approximately neutral, are nontoxic to living protoplasm, are short-chain carbon compounds and contain available phosphorus in excess of 0.01 p.p.m. and nitrogen in excess of 0.2 p.p.m. As a substance is removed more and more distant from these conditions, fewer and fewer kinds of organisms use it as a source of energy, until at the greatest extremes of environment, the compound is virtually unassailable."

The authors have further requested that acknowledgment be given the National Institutes of Health, sponsors of the research project reported by the paper.

EFFICIENCY OF A SMALL HIGH-RATE TRICKLING FILTER PLANT AT JERUSALEM, ISRAEL

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As a result of large scale immigration, sewage disposal in Jerusalem had become an urgent problem in 1950, and the small high-rate trickling filter plant which is the subject of this study was constructed in that year. The plant is situated in the Valley of the Cross on the outskirts of Jerusalem. It was primarily intended as a pilot plant, in order that its performance, and the experience gained in operating it, might help to determine the design of sewage treatment plants to be built in Israel in the future.

The treatment plant was designed in 1949 by the Department of Public Works to treat 26,400 gal. of sewage per day. At that time, one year after the siege of Jerusalem, there was still a serious water shortage in the city, and the average consumption was 8.0 gal. per capita per day. The 5-day B.O.D. of the sewage was estimated at 1,800 p.p.m., and the daily B.O.D. load at the plant at 395 lb. It was assumed that primary settling would remove 35 per cent of the load. The design basis for the filters was 3.23 lb. per cubic yard of medium per day, making the volume of filter medium 79.5 cu. yd.

Laboratory analyses made in 1951 showed that the predominantly domestic Jerusalem sewage was indeed very concentrated; the B.O.D. values of composite samples ranged between 876 and 1,970 p.p.m., with a median of 1,446 p.p.m. The sewage was generally septic, as many of the houses are connected to septic tanks or percolating pits, from which the overflow discharges into the sewers.

The investigation reported here extended from May 27 to October 15, 1952. Its main objectives were: (a) to examine the feasibility of treating Jerusalem's highly concentrated and septic domestic sewage on high-rate trickling filters; (b) to study the performance of the filters as compared with those in the United States; (c) to study the effect of varying operating conditions, in particular the B.O.D. loading and the recirculation ratio, on the efficiency of treatment. The first two objectives are dealt with in Part I of this study, the third in Part II.

Plant Operation

The treatment plant is situated on a slope, thereby permitting gravity flow to and through the various treatment units. The facilities consist of the following units: bar-screen with 1-in. spacing; one rectangular hopper-bottomed primary settling tank with hydrostatic sludge removal; two filters in parallel with four-arm rotary distributors; one secondary settling tank, identical with the primary tank; and a recirculation compartment and pump. Part of the secondary effluent is returned to a point just below the outlet weir of the primary tank; the remaining part passes over a V-notch into an effluent sump. A flow diagram for the plant is given in Figure 1. Because of budgetary limitations, no grit chamber was built.

The settling tanks, which have no in-

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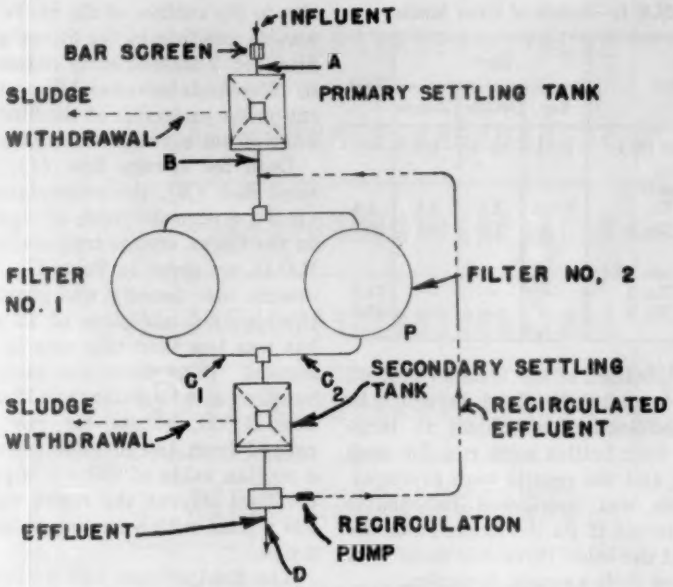

FIGURE 1.—Schematic layout of pilot trickling filter plant.

let weir, are each 13.125 ft. by 6.625 ft. in area. The depth to the hopper is 3.28 ft. and the hopper itself is an additional 3.3 ft. deep. Primary effluent mixed with the recirculated flow enters a division box where the sewage flow is divided between the two filters. The filter medium is hard crushed limestone. The filters, designated as Nos. 1 and 2, are 16.4 ft. in diameter and were originally constructed alike. However, the top layer was removed from filter No. 1 before this investigation began. The arrangement and volumes of filtering media are given in Table I.

Throughout this investigation, sludge was withdrawn from both tanks every 2 hr. during the daytime and occasionally at night.

Flow Control and Measurement

Sewage flow was regulated at a control manhole at the entrance to the plant, where a 12-in. main sewer was intercepted. The flow was measured by the rise in water level in the primary settling tank, the effluent recirculating pump being shut off during the interval. Hourly measurement and regulation kept the flow constant during the greater part of the day. At night, however, the flow in the main sewer usually was insufficient to maintain the required flow through the plant.

Recirculation, measured by the drop in water level in the recirculation compartment, was adjusted to the desired rate by means of a gate valve in the recirculation line.

Sampling

Sewage samples were collected regularly at the following points: (a) raw sewage inlet; (b) primary effluent; (c) filter No. 1 effluent; (d) filter No. 2 effluent; and (e) final effluent. Fractional samples were collected hourly, composited according to flow and stored in an ice box. At the end of a 24-hr. period samples were brought to the laboratory for analysis.

Chemical Methods

Standard analytical methods were employed (1), using the Rideal-Stew-

TABLE I.—Details of Filter Media

Item	Layer			Total
	Top	Middle	Bottom	
Stone size (in.)	¾–1½	1½–4	4–6	—
Thickness (ft.)				
Filter No. 1	None	3.3	1.1	4.4
Filter No. 2	1.3	3.3	1.1	5.7
Volume (cu. yd.)				
Filter No. 1	—	—	—	34.5
Filter No. 2	—	—	—	45.0

art modification of the Winkler method for determining dissolved oxygen. As this modification is subject to large errors, four bottles were run for each sample, and the results were averaged. A result was considered improbable and rejected if its deviation from the mean of the other three was more than 2.5 times their average deviation.

Dissolved oxygen was determined on grab samples tested on the spot. Settleable solids by volume were read daily on grab samples at the plant. Total nitrogen and nitrites plus nitrates were determined occasionally on composite samples.

Temperature

A maximum-minimum thermometer was immersed in the sewage at the outlet of one of the filters and read daily.

I. PLANT PERFORMANCE

The experimental program consisted of increasing the flow of sewage through the plant by stages, the recirculation ratio being kept at the desired rate. As a rule, no samples were collected for the first three days after the recirculation flow rate had been altered.

During the investigation, the settling tanks were emptied and cleaned once, and the grit removed. The filters were thus removed from operation for one day, after which no samples were taken for a period of 8 days. Following the cleaning, however, gas bubbles and masses of dark sludge continued to rise to the surface of the tanks. There was no ponding in the filters, although filter No. 2 showed early indications of it. *Psychoda* larvae and flies were present on the underside of the filter stones, but did not constitute a nuisance.

Data for sewage flow (I), recirculated flow (R), the recirculation ratio (R/I), hydraulic rate of application on the filters, sewage temperatures, and B.O.D. are given in Table II. The hydraulic rate usually was greater than the required minimum of 12 m.g.a.d., but was less than this rate in five instances. (The plant was incapable of handling a flow greater than 19 m.g.a.d.) The B.O.D. values for raw sewage ranged from 480 to 1,348 p.p.m., with a median value of 950 p.p.m.; and for the final effluent the range was 99 to 325 p.p.m., with a median value of 195 p.p.m.

The final effluent had a slight odor and a yellowish-brown color. The total nitrogen content of the effluent was about 150 p.p.m., and nitrites plus nitrates were less than 0.5 p.p.m. Settleable solids ranged between 1 and 2 ml. per liter. Dissolved oxygen was not found in the effluent.

Primary Settling

Table III gives performance data for the primary settling tank. (The B.O.D. values for raw sewage and settled effluent are reported in Table II). It can be shown that there is no relation between the overflow rate (and consequently the detention period) and the percentage B.O.D. removal. As may be seen from Figure 2, the percentage removal is directly proportional to the B.O.D. of the raw sewage. The calculated coefficient of correlation r is + 0.716, and can be shown to be highly significant. The standard deviation of a single measurement is 12.38 per cent.

In Table VI the performance of the Jerusalem plant is compared with that of various plants in the United States. It is obvious that the Jerusalem primary settling tank ranks among those

TABLE II.—Flow, Temperature and B.O.D. Data [1]

Sampling No.	Days from Start of Investigation[2]	Sewage Flow (g.p.d.)	Recirc. Flow (g.p.d.)	Recirc. Ratio	Hydraulic Rate (m.g.a.d.)	Temperature (°C.)			5-Day B.O.D. (p.p.m.)				
						Max.	Min.	Avg.	Raw Sewage (a)	Primary Effluent (b)	Filter No. 1 Effl. (c_1)	Filter No. 2 Effl. (c_2)	Final Effl. (d)
1	0	26,300	72,500	2.76	10.1	23	18	20.5	878	654	141	128	106
2	5	29,860	72,500	2.43	10.5	26	21	23.5	777	645	151	117	99
3	12	35,560	95,800	2.70	13.6	24	18	21.0	1,093	940	286	299	305
4	18	33,330	95,800	2.88	13.4	23	17	20.0	817	571	230	220	206
5	29	36,680	95,800	2.61	13.6	24	18	21.0	1,066	600	232	269	228
6	41	46,850	125,000	2.67	17.7	—	—	—	805	537	183	168	154
7	55	51,700	125,000	2.42	18.2	24	23	23.5	885	610	234	213	197
8	62	53,400	125,000	2.34	18.2	28	21	24.5	765	585	128	133	129
9	66	49,900	125,000	2.50	17.7	28	21	24.5	735	608	132	134	120
10	77	48,950	62,300	1.27	11.2	27	22	24.5	953	673	204	210	180
11	80	48,300	62,300	1.29	11.2	28	22	25.0	904	503	204	201	167
12	84	49,300	62,300	1.26	11.2	28	24	26.0	950	620	186	204	183
13	90	64,900	68,400	1.05	14.2	30	19	24.5	983	640	185	192	164
14	92	65,100	68,400	1.05	14.2	28	24	26.0	1,090	645	234	234	195
15	95	58,000	68,400	1.18	13.7	28	24	26.0	480	423	134	145	163
16	98	55,900	68,400	1.22	13.7	29	21	25.0	1,080	640	285	327	275
17	102	60,100	68,400	1.14	13.7	28	22	25.0	1,260	560	179	196	113
18	106	69,900	93,250	1.33	16.9	20	21	24.5	1,217	705	309	352	325
19	120	69,500	93,250	1.35	16.8	28	25	26.5	1,030	960	326	320	273
20	126	70,400	107,100	1.52	18.3	—	—	—	1,348	725	347	335	297
21	141	76,250	107,100	1.41	18.9	—	—	—	—	618	198	226	185

[1] May 27 to October 15, 1952.
[2] Settling tanks cleaned, 20th and 21st day.

TABLE III.—Primary Settling Tank Data

Sampling No.	Overflow Rate (gal./sq. ft./day)	Theoretical Detention Period (hr.)	B.O.D. Removal (%)
1	305	3.4	26.8
2	346	3.0	17.0
3	412	2.5	33.8
4	381	2.7	30.1
5[1]	426	2.4	43.6
6	544	1.9	33.3
7	600	1.7	31.0
8	620	1.7	23.6
9	529	1.8	17.6
10	568	1.8	29.4
11	560	1.8	44.4
12	573	1.8	34.7
13	752	1.4	38.0
14	755	1.4	40.5
15	674	1.5	11.9
16	649	1.6	39.1
17	696	1.5	55.6
18	411	1.3	42.1
19	806	1.3	6.8
20	816	1.3	46.3
21	885	1.2	—
Avg.	—	—	32.3

[1] Settling tanks cleaned prior to this sampling.

tanks with poor performance. Considering the fact that in Jerusalem the raw sewage B.O.D. is much higher than is generally the case in the United States, the percentage removal by primary settling would be expected to be at least as great. This, however, was not the case. The poor performance is probably due to unsatisfactory sludge removal, to the absence of an inlet weir and an adjustable outlet weir, and to other unsatisfactory design details.

Secondary Treatment

Measures of Performance

According to standard practice (2), the filter loadings are based on the B.O.D. of the settled raw sewage and do not include recirculated flow.

In the following formulae, filter loadings and removals are expressed in pounds of 5-day B.O.D. per cubic yard of medium per day, and are divided by 2, as only one-half the flow goes to each filter. The subscripts 1 and 2, when added to c or V, refer to filters Nos. 1 and 2, respectively. $V_1 = 34.5$ cu. yd. and $V_2 = 45.0$ cu. yd. The symbols used are as follows:

b, c, d = p.p.m. B.O.D. of primary effluent, filter effluent, and final effluent, respectively.
V = volume of filter medium, cu. yd.
I = plant influent, g.p.d.
R = recirculation flow, g.p.d.

The filter loading, X, is obtained by means of the expression

$$X = \frac{8.345\,bI}{2V} \times 10^{-6} \qquad (1)$$

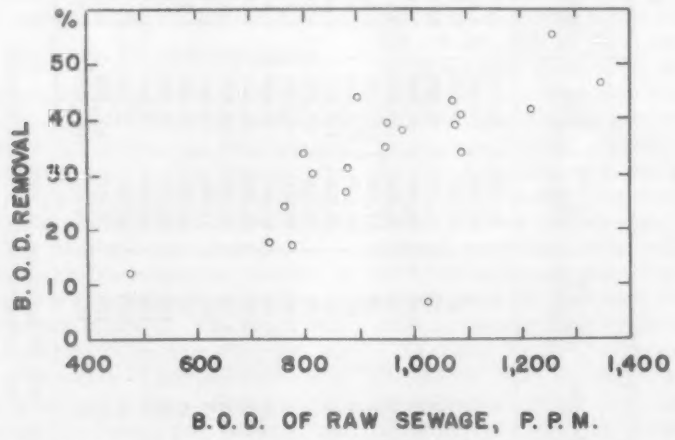

FIGURE 2.—Percentage removal of 5-day B.O.D. by primary settling.

For each filter only, the removal y' is given by

$$y' = \frac{8.345\ (bI + dR) - c(I + R)}{2V} \times 10^{-6} \quad (2)$$

The efficiency (per cent) for the filters only is therefore

$$\frac{(bI + dR) - c(I + R)}{bI} \times 100 \quad (3)$$

For secondary treatment as a whole (filter plus secondary settling), the B.O.D. removal, y, is given by

$$y = \frac{8.345\ [(bI + dR) - d(I + R)]}{2V} \times 10^{-6}$$

$$y = \frac{8.345(b - d)I}{2V} \times 10^{-6} \quad (4)$$

Therefore, the over-all efficiency (per cent) of filters plus secondary settling equals

$$\frac{(b - d)}{b} \times 100 \quad (5)$$

The difference between the two efficiencies, Eqs. 5 and 3 equals

$$\frac{(c - d)(I + R)}{bI} \times 100 \quad (6)$$

This value is the contribution of secondary settling to the efficiency of filter treatment.

Filter Efficiency

The effluents c_1 and c_2 (Table II) were compared, using Student's t-test for paired differences (3). The value of t was found to be 1.222, which corresponds to a probability of about 25 per cent that the differences between the effluents could have occurred by chance alone. The B.O.D.'s of the effluents may therefore be assumed not to differ significantly. As the other terms in Eq. 3 are common to both filters, the efficiencies may also be considered to be the same. Therefore filter No. 2, with its greater depth and additional layer of small-sized crushed stone, has no advantage over filter No. 1. On the contrary, it has the disadvantage in practice that it tends to become ponded, and costs more to build.

Data relating to the performance of the filters only are given in Table IV, which also contains some data reproduced for convenience from Table II. The average efficiency based on filter No. 1 data is 60.8 per cent, and the efficiency of filter No. 2 is not significantly different. The standard deviation of a single sampling is 10.7 per cent. It may be seen from Table VI that the efficiency, filters only, compares favorably with that of single-stage filters in the United States.

When secondary treatment at the plant is studied as a whole, difficulty arises in calculating removals and efficiencies, since both filters have a common secondary settling tank. It has been shown previously that the B.O.D. of the effluent of one filter does not differ significantly from that of the other filter. Since the filter effluents were obtained from the same primary effluent, it is logical to assume that under identical secondary settling conditions each filter would discharge the same amount of B.O.D. The final effluent may therefore be looked upon as the mixture of two effluents, obtained by settling each filter effluent separately.

An inspection of Eqs. 1, 4 and 5 shows that B.O.D. loadings and removals for the filters (plus secondary settling) are not the same for both filters, but that the efficiencies are the same. The B.O.D. loadings, removals, and efficiencies for secondary treatment as a whole are given in Table V.

The average efficiency of secondary treatment is 69.8 per cent, with a standard deviation of single measurement of 8.5 per cent. For purposes of statistical quality control (4) the 99.73 per cent confidence limits are set at $69.8 \pm 3 \times 8.5$ or 44.3 and 95.3 per cent. As the average efficiency for the filters only is 60.8 per cent, the percentage removal of B.O.D. by sec-

TABLE IV.—Performance of Filters Only

Sampling No.	Temp. (°C.)	Recirc. Ratio	Filter No. 1		Filter No. 2		Efficiency[1] (%)
			Loading (x)	Removal (y')	Loading (x)	Removal (y')	
			(lb. B.O.D./cu.yd./day)				
1	20.5	2.76	2.08	1.32	1.59	1.13	63.4
2	23.5	2.43	2.33	1.33	1.79	1.34	57.1
3	21.0	21.70	4.04	3.03	3.10	2.17	75.0
4	20.0	2.88	2.30	1.08	1.76	0.95	47.0
5	21.0	2.61	2.66	1.59	2.04	0.76	59.8
6	—	2.67	3.04	1.57	2.33	1.44	51.6
7	23.5	2.42	3.81	1.79	2.92	1.72	47.0
8	24.5	2.34	3.78	2.97	2.90	2.19	78.6
9	24.5	2.50	3.67	2.69	2.81	2.03	73.3
10	24.5	1.27	3.98	2.60	3.05	1.93	65.3
11	25.0	1.28	2.94	1.47	2.25	1.16	50.0
12	26.0	1.26	3.70	2.57	2.83	1.78	69.5
13	24.5	1.05	5.02	3.40	3.85	2.52	67.7
14	26.0	1.05	5.07	2.91	3.89	2.23	57.4
15	26.0	1.18	2.97	2.39	2.27	1.61	80.5
16	25.0	1.22	4.33	2.32	3.32	1.30	53.6
17	25.0	1.14	4.07	2.22	3.12	1.50	54.5
18	24.5	1.33	5.95	3.53	4.55	2.05	59.3
19	26.5	1.35	8.07	4.73	5.91	3.72	58.6
20	—	1.52	6.18	2.58	4.51	2.17	41.7
21	—	1.41	5.70	3.70	4.37	2.36	64.9
Avg.	—	—	—	—	—	—	60.8

[1] Based on filter No. 1.

ondary settling based on settled raw sewage is 69.8 − 60.8 = 9.0 per cent.

Table VI shows that the efficiency of the Jerusalem filters compares favorably with corresponding results from the United States (5)(6), but that secondary settling is poor; even more so than primary settling. This poor performance lowers the efficiency of secondary treatment as a whole. Because the secondary tank was operated at the high overflow rate of 1,140 to 2,120 gal. per square foot per day, it is probable that this rate was responsible for the poor performance. To this must be added the unsatisfactory sludge removal, the absence of an inlet weir and an adjustable outlet weir, and other unsatisfactory design details.

Over-all Plant Efficiency

Data for over-all plant efficiency are given in Table V. The average over-all plant efficiency is 79.1 per cent. The standard deviation of a single sampling is 6.2 per cent. It may be seen that the over-all plant efficiency is more regular than the efficiency of secondary treatment, or that of the filters only. This is probably due to the combined effect of primary and secondary treatment: when the B.O.D. removal by primary settling is high, the removal by secondary treatment (as distinct from the efficiency) is low, and vice versa.

Discussion of Plant Performance

The feasibility of treating Jerusalem's highly concentrated and septic domestic sewage by high-rate trickling filters may be conveniently considered under two headings: (a) the performance of the filters and (b) the quality of the final effluent. Regarding the performance of the filters only, the per-

TABLE V.—Filter Loadings and Removals and Over-all Plant Efficiency

Sampling No.	Filter No. 1		Filter No. 2		Secondary Treatment, Efficiency (%)	Over-all Efficiency[1] (%)
	Loading (x)	Removal (y)	Loading (x)	Removal (y)		
	(lb. B.O.D./cu.yd./day)					
1	2.08	1.74	1.59	1.33	83.7	87.9
2	2.33	1.97	1.79	1.51	84.5	87.3
3	4.04	2.73	3.10	2.09	67.6	72.1
4	2.30	1.48	1.76	1.13	64.3	74.9
5	2.66	1.65	2.04	1.27	62.0	78.6
6	3.04	2.17	2.33	1.66	71.4	80.9
7	3.81	2.58	2.92	1.98	67.7	77.7
8	3.78	2.94	2.90	2.26	77.8	83.1
9	3.67	2.95	2.81	2.26	80.4	83.7
10	3.98	2.92	3.05	2.24	73.4	81.1
11	2.94	1.96	2.25	1.50	66.6	81.5
12	3.70	2.61	2.83	2.00	70.5	80.7
13	5.02	3.74	3.85	2.86	74.5	83.3
14	5.07	3.54	3.89	2.72	69.8	82.1
15	2.97	1.82	2.27	1.40	61.3	66.0
16	4.33	2.47	3.32	1.89	57.0	74.5
17	4.07	3.25	3.12	2.49	79.9	91.0
18	5.95	3.21	4.55	2.46	53.9	73.3
19	8.07	5.77	5.91	4.43	71.5	73.5
20	6.18	3.64	4.51	2.79	58.9	78.0
21	5.70	3.99	4.37	3.06	70.0	70.1
Avg.	—	—	—	—	69.8	79.1

[1] Based on raw sewage and final effluent.

centage reduction of B.O.D. compared favorably with that for filters in the United States (60.8 per cent). If instead of the 9.0 per cent B.O.D. removal by secondary settling in this study, a removal of 17 to 18 per cent could be considered, an efficiency of 78 to 79 per cent would be obtained. This is in agreement with Velz's value (7) for the fraction of the B.O.D. removable by high-rate trickling filters (78.4 per cent for filters plus secondary settling).

Regarding the quality of the final effluent, as previously mentioned, it had a light color and slight odor. The B.O.D. was high (99 to 325 p.p.m.; median 195 p.p.m.). As a result, the effluent contained no dissolved oxygen and the concentration of nitrites plus nitrates was low. These characteristics, however, should not be taken as evidence of poor filter performance.

Given proper settling conditions, especially secondary settling, the settleable solids and B.O.D. of the final effluent would be substantially reduced. If an over-all plant efficiency of 86 per cent and an average raw sewage B.O.D. of 950 p.p.m. is assumed, the final effluent would still have an average B.O.D. of about 130 p.p.m. This is a high value, but the production of an effluent similar in strength to that of trickling filter effluents in the United States would be both difficult and impractical.

The final effluent from the plant was used for irrigation or was discharged into a dry creek bed near the city and did not constitute a nuisance.

II. STATISTICAL ANALYSIS

The recirculation ratio and B.O.D. loading of this plant have been analyzed statistically for their effects on the efficiency of the filters. The conclu-

TABLE VI.—Comparative Efficiency of Units in the Jerusalem Plant and in Trickling Filter Plants in the United States [1]

Treatment Plants		Primary Treatment			Secondary Treatment[2]						Over-all Plant Treatment	
		No. Plants	Avg. (%)	Med. (%)	Filters Only		Filters plus Secondary Settling		Secondary Settling Only			
Type	No.				Avg. (%)	Med. (%)	Avg. (%)	Med. (%)	Avg. (%)	Med. (%)	Avg. (%)	Med. (%)
Military Plants[3]:												
Deep filters	7–10	10	39.1	35.6	58.0	58.3	77.5	74.6	22.0	18.3	86.2	87.8
Shallow filters	5–6	—	—	—	59.9	56.3	75.8	80.7	21.1	17.4	81.3	86.0
Other plants[4]	8	6	34.8[5]	35.0[5]	—	—	83.5	83.1	—	—	89.5	89.2
Elizabethtown, Ky.[6]	1	1	49.3–49.5		46.3–52.8		51.5–63.5		5.2–10.7		75.5–81.8	
Jerusalem, Israel	1	1	32.3		60.8		69.8		9.0		79.1	

[1] Averages and medians refer to groups of plants. Individual plants are represented by a single value.

[2] When a variable number of plants is involved the average B.O.D. removal by secondary settling only does not equal the difference between the averages for filters plus secondary settling and filters only.

[3] See Ref. 2.

[4] See Ref. 5.

[5] Estimate taking recirculation through primary tank into account.

[6] See Ref. 6.

sions drawn are discussed in the light of Velz's basic law for biological filter beds (7).

Filter efficiencies are calculated as the slope of the line of least squares, relating B.O.D. removals to loadings. The value so obtained is somewhat different from the average efficiency of individual samplings, but it is more precise and better suited to statistical comparison. Calculations are made from data given in Table IV. The statistical methods used are those described by Youden (8).

The variable factors were studied separately by arranging and rearranging B.O.D. loadings and removals into groups, according to the magnitude of the variable in question; the other factors remaining nearly constant, or having been shown to have no effect. It could be shown that all lines pass through the origin. Centralized variables thus became unnecessary, and the slope of the line of least squares was calculated according to the formula $\frac{\Sigma xy}{\Sigma x^2}$. The efficiencies, that is, slopes, were compared for two groups at a time by means of the t-test.

Data

Temperature Variable

An inspection of Table IV shows that samplings having a recirculation ratio of about 2.5 may be separated into two groups according to the daily sewage temperature: the first has a daily sewage temperature of 20 to 21° C. (Samplings 1, 3, 4, 5), and the second a daily sewage temperature of 23.5 to 25.0° C. (Samplings 2, 7, 8, 9). The two groups were studied separately, in the following analysis, and their slopes (efficiencies) were found to be identical (Figure 3). For the purposes of this study, points belonging to either of the two temperature groups could be pooled. In view of the small difference in temperature, no conclusions are drawn as to the effect of temperature in general.

Recirculation Ratio Variable

The samplings were divided into two groups according to the magnitude of

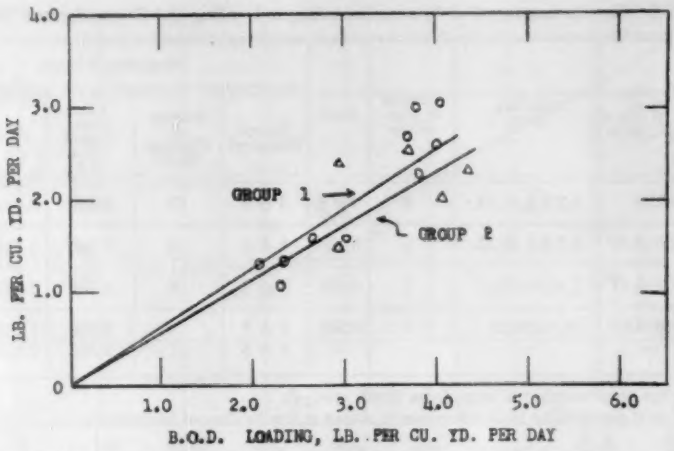

FIGURE 3.—Relationship between B.O.D. loading and B.O.D. removal; two recirculation ratios.

the recirculation ratio, R/I (R = recirculation flow, and I = inflow in gallons per day. Group 1 had a recirculation ratio of about 2.5 (Samplings 1 to 9); and Group 2 had a recirculation ratio of about 1.3 (Samplings 10, 11, 12, 15, 16, 17). Loadings were generally lower at a recirculation ratio of 2.5, the maximum loading for Group 2 being 4.04 lb. of B.O.D. per cubic yard per day. In order to eliminate any possible effect of the loading, no loadings at the recirculation ratio of about 1.3 greater than 4.10 lb. of B.O.D. per cubic yard per day are included in Group 2. The slopes were found to be: Group 1, 0.639; and Group 2, 0.612 (see Figure 3).

Comparison of Slopes

The value of t., 13 degrees of freedom, is equal to 0.439. This value corresponds to a probability of more than 0.50 that the difference is due to chance fluctuation; a difference in slope is not indicated and points may be pooled.

B.O.D. Loading Variable

In Table VII samplings are grouped according to the magnitude of the loading. According to Velz (7), the rate of extraction of B.O.D. by the filter, up to a certain limiting load, is proportional to the extractable fraction remaining. Hence, the percentage removal for a filter of given depth is a constant. The limiting load is directly proportional to the temperature. At 26° C. this load appears to be in the vicinity of 0.89 lb. of B.O.D. per square foot per day. In the case of filter No. 1 this is equivalent to 5.47 lb. per cubic yard per day, the value chosen as the upper limit of Group 5. Group 6, it is evident, consists of loadings above Velz's limiting load.

When the slopes of the four groups of data arranged according to loading are compared (Table VII; Figure 4), those of Groups 3, 4, and 5 (the groups with loadings up to Velz's limiting value) are so close that they may be regarded as equal. In fact, it is not necessary to use a statistical test to compare the slopes of Groups 3 and 5. In the first three groups, therefore, a straight-line relationship may be seen to exist between loading and removal. Group 6 has the lowest slope of all.

A comparison with Group 4 (the group with the highest slope) shows that there is a 0.25 probability that the difference is due to chance fluctuations; thus, a difference in slope is not dem-

TABLE VII.—Arrangement of Groups According to Loading and Comparison of Slopes

Group	Loading Range (lb. B.O.D./ cu.yd./day)	Sampling (No.)	Number of Samplings	Slope	Comparison of Slopes				
					Groups Compared	Degrees of Freedom (Σn-2)[1]	5 Per Cent Critical Value of t	t	Probability[2] (%)
3	0–2.99	1,2,4,5,11,15	6	0.606	3 & 4	10	2.228	0.549	>50
4	3.00–3.99	6,7,8,9,10,12	6	0.648	4 & 5	9	2.262	0.511	>50
5	4.00–5.47	3,13,14,16,17	5	0.616	3 & 6	8	2.306	0.547	>50
6	5.48–8.07	18,19,20,21	4	0.562	4 & 6	8	2.306	1.239	25
	—	—	—	—	5 & 6	7	2.365	0.862	40

[1] Σn, the total number of samplings (both groups).
[2] Per cent probability that difference in slopes is due to chance fluctuations.

onstrated. When the first three groups are pooled, a slope of 0.626 is obtained. A comparison of this with the slope of Group 6 shows that there is a probability of 0.15 that the difference is due to chance alone; thus, no difference in slope is demonstrated.

Discussion of Statistical Analysis

The straight-line relationship, up to Velz's limiting load for maximum efficiency, shown to exist between B.O.D. loading and removal is in agreement with Velz's basic law (in the case of filter No. 1, 5.47 lb. of B.O.D. per cubic yard of medium per day at 26° C.). The limiting load is exceeded for 35 successive days from Sampling 18 onward (Group 6; Tables II, IV, and VII). A peak load of 8.07 lb. per cubic yard of medium per day (the equivalent of 1.31 lb. per square foot) is

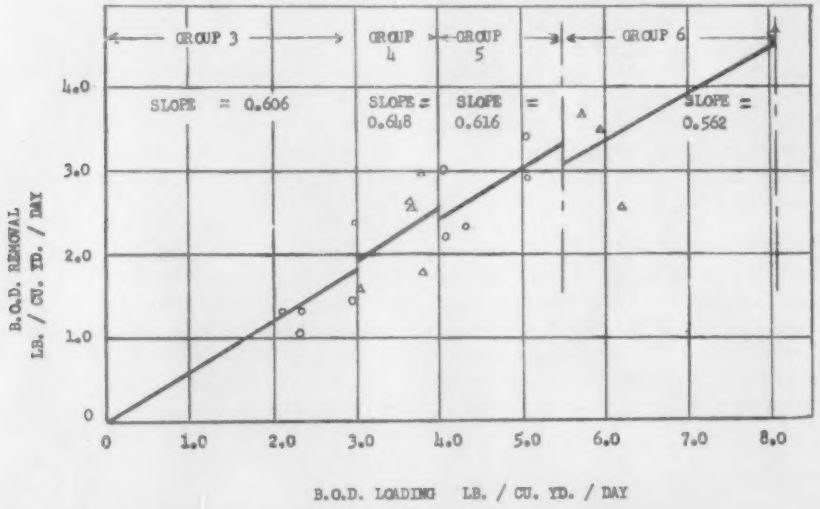

FIGURE 4.—Relationship between B.O.D. loading and B.O.D. removal; four loading groups.

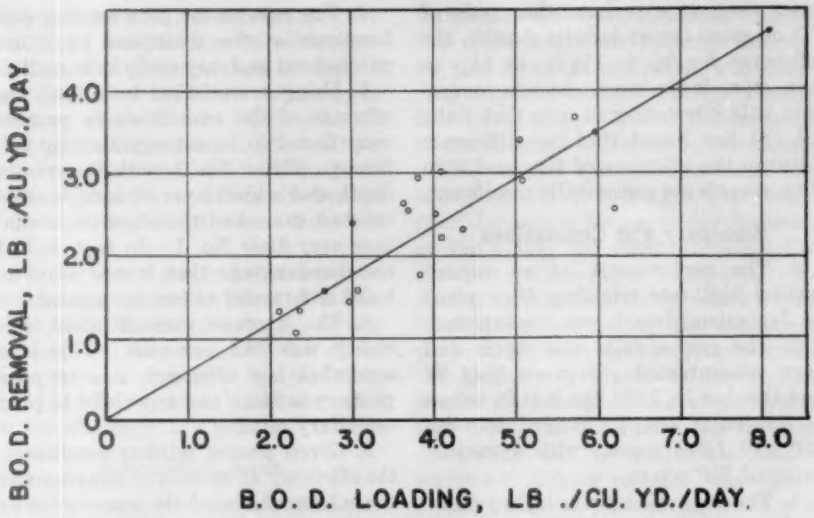

FIGURE 5.—Relationship between B.O.D. loading and B.O.D. removal; total of all points.

obtained in Sampling 19, with no detriment to filter efficiency. It is only Sampling 20, with its very low efficiency (41.7 per cent), that reduces the slope of Group 6. When all points below Velz's limiting load (17 points) are compared with the points above it (4 points), there is a probability of about 0.15 that this decrease in slope is due to chance fluctuation. Furthermore, as the 95 per cent confidence limits for a single efficiency determination are 39.4 and 88.2 per cent, it can be shown that there is a probability of more than 0.50 that among any four samplings (such as those comprising Group 6) one such low value will occur. It should be noted that the efficiency is high again in Sampling 21, which was taken 15 days after Sampling 20. On the evidence available in this study, a decrease in slope is not demonstrated, and it appears that the same straight-line relationship between B.O.D. loading and removal extends considerably beyond Velz's limiting load.

According to Velz's law, when the depth of a filter exceeds 9 ft., or when recirculation is such as to produce the same effect, the limit of removal for infinite depth or by repeated recirculation is approached. Thus, for filter No. 1 a recirculation ratio of 1.3 indicates an effective depth of 4.4 ft. + 4.4 ft. + 1.3 ft. = 10.1 ft. This explains why the efficiency of the filters remained unchanged when the recirculation ratio was decreased from 2.5 to 1.3.

When all the points for each filter are pooled, a slope of 0.598 is obtained for filter No. 1 (Figure 5) and 0.577 for filter No. 2. The value of t, 40 degrees of freedom, equals 0.644. This is equivalent to a probability of more than 0.50 that the difference is due to chance; there is, therefore, no significant difference between the slopes. Indeed, this also follows from the conclusion arrived at in Part I, Eq. 3, that the B.O.D. values of the effluents did not differ significantly. It will be recalled that filter No. 2 differs from filter No. 1 in that it has a layer of ¾- to 1½-in. crushed stone on top of the 1½- to 4-in. stone present in both. The fact that the efficiencies of both filters do not differ significantly indi-

cates that, at a recirculation ratio of 1.3 or more (or at infinite depth), the efficiency for ¾- to 1½-in. or 1½- to 4-in. stone is the same. In this connection it is interesting to note that Fairall (9) has found that the difference between the efficiency of 4-in. and 2- to 3-in. stone is not statistically significant.

Summary and Conclusions

1. The performance of an experimental high-rate trickling filter plant in Jerusalem, Israel, was investigated.

2. The raw sewage was septic and very concentrated. Between May 27 and October 15, 1952, the B.O.D. values of composite samples ranged between 480 and 1,348 p.p.m., with a median value of 950 p.p.m.

3. The final effluent was light yellowish-brown in color and had a slight odor. The effluent B.O.D. ranged between 95 and 325 p.p.m., with a median value of 195 p.p.m. Settleable solids amounted to 1 to 2 ml. per liter, total nitrogen was about 150 p.p.m., and nitrites plus nitrates totaled less than 0.5 p.p.m. (not more than in raw or settled sewage). The final effluent contained no dissolved oxygen.

4. Primary settling removed 32.3 per cent of the B.O.D. The percentage removal was directly proportional to the B.O.D. of the raw sewage, with a highly significant coefficient of correlation r of $+0.716$. Compared with settling tanks in the United States, the Jerusalem tank performed poorly.

5. A series of increased loadings was applied to the filters with a maximum of 8.07 lb. of 5-day B.O.D. per cubic yard of medium per day. The average efficiency of only the filters was 60.8 per cent, and of the filters plus secondary settling 69.8 per cent. Thus the percentage removal of B.O.D. by secondary settling, based on primary effluent, was 9.0 per cent. A comparison with data from filters in the United States shows the filters themselves functioned properly, but that secondary settling was very poor.

6. The reasons for poor settling performance at the treatment plant are pointed out and may easily be remedied.

7. Using a statistical technique, the effluents of the two filters in parallel were found to be not significantly different. Filter No. 2, with its greater depth and added layer of smaller-sized crushed stone had therefore no advantage over filter No. 1. In fact, it had the disadvantage that it cost more to build and tended to become ponded.

8. The average over-all plant efficiency was 79.1 per cent. This is a somewhat low efficiency, due to poor primary settling and especially to poor secondary settling.

9. Given proper settling conditions, the efficiency of secondary treatment as a whole would be of the same order as Velz's value for the B.O.D. fraction removable by high-rate trickling filters (78.4 per cent). The settleable solids and B.O.D. of the final effluent would be substantially reduced. However, since the B.O.D. of the raw sewage is high (950 p.p.m.), the final effluent would still be high (130 p.p.m. at an over-all plant efficiency of 86 per cent); reduction to the strength of trickling filter effluents in the United States would be difficult and impractical.

10. The effluent did not constitute a nuisance when discharged into a dry creek bed near the city.

11. A statistical analysis of efficiency data for the filters only shows that the efficiency was the same for recirculation ratios of about 1.3 and 2.5.

12. At increased loadings up to 5.47 lb. of B.O.D. per cubic yard of medium per day a straight-line relationship is shown to exist (equivalent, in the case of filter No. 1, to 0.89 lb. per square foot per day, or Velz's limiting load for maximum efficiency). This is in agreement with Velz's basic law.

13. When all points below Velz's limiting load are pooled (17 points), a slope of 0.626 is obtained. Above this load (4 points, peak load 8.07 lb. per cubic yard of medium per day or 1.31

lb. per square ft.) the slope is 0.562. Statistical analysis has failed to demonstrate that this decrease in slope is significant, and the lower value may be due to a single chance fluctuation. It appears that the straight-line relationship found between B.O.D. loading and removal extends considerably beyond Velz's limiting load for maximum efficiency.

14. When the recirculation rate was such as to produce the effect of a filter depth of 9 ft. (infinite depth, according to Velz) or more, the size of the filter medium (whether ¾- to 1½-in. or 1¼- to 4-in. stone) had no effect on the efficiency.

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Industrial Wastes

WASTE TREATMENT AT A LARGE CHEMICAL MANUFACTURING PLANT *

By J. H. Steen, F. M. Majewski, and T. Iezzi

Rohm & Haas, Bristol, Pa.

Waste treatment at a large chemical manufacturing plant, such as the Rohm & Haas plant at Bristol, Pa., includes a multitude of operations in addition to the treatment of dilute aqueous wastes. These were discussed in some detail in a previous paper (1) and therefore are only listed here. They include the following:

1. Spent sulfuric acid, which is converted to ammonium sulfate.
2. Spent phosphoric acid, which is recovered in the form of usable phosphates.
3. Waste solvents, which are burned, if not recoverable by distillation.
4. Solid waste, which is disposed of by sanitary land fill.

In addition, air pollution is prevented by passing contaminated gases through appropriate scrubbers. Installations of this type are in use at the methyl amines plant, the ammonium sulfate plant, and the zinc oxide plant. Precipitators are used at the power plant to remove fly ash.

This paper, however, is confined to the handling and treatment of the dilute organic wastes in aqueous solution resulting from the many chemical manufacturing processes at the Bristol plant. These processes include manufacture of industrial chemicals for use in agriculture, textiles, plastics, oil, leather, paint, and allied industries.

Three Sewer Systems

The Bristol plant is serviced by three independent sewer systems. Sanitary waste is collected and pumped to the Bristol Borough sewage treatment works for disposal. All clean non-contaminated process water is discharged directly to the Delaware River by means of the plant or clean water sewer. The third, the chemical sewer system, receives contaminated aqueous waste for eventual treatment.

No Losses Permissible

In discussing the problem of aqueous waste treatment at this plant, it is essential that its geographic location be kept in mind. Located along the Delaware River immediately above the Burlington-Bristol Bridge, it is within a few miles of the intakes of two waterworks supplying Bristol and Philadelphia. Therefore, it is necessary that the plant effluent not only be satisfactory from the viewpoint of its B.O.D., but in addition it must contain no chemicals which would impart a taste or odor to water or which could be considered to be toxic.

Consequently, waste treatment at the Bristol plant not only requires proper treatment of waste, but also requires that no accidental loss of chemicals to the river be permitted. Buildings in which chemicals are handled which

* Presented at 1955 Annual Meeting, Pennsylvania Sewage and Industrial Wastes Assn.; State College, Pa.; Aug. 22–24, 1955.

would create a problem if accidentally lost to the river are protected either by having no sewer, or by having all open drains or floor drains tied into the chemical sewer system. All tanks handling chemicals of this type are diked as a precaution against failure or accidental overflow. Receiving tanks are protected by high-level alarms which will close down the transfer pumps. Drums containing objectionable materials are stored in special locations which are connected to the chemical sewer system. These measures serve to prevent accidental losses to the river.

Waste Sources

The aqueous chemical waste is a complex mixture consisting mainly of aliphatic acids, alcohols and esters plus some inorganic salts and some small amounts of miscellaneous materials such as benzene and allied ring compounds, complex organic amines, and fermenter wastes. The waste contains sufficient available nitrogen and phosphorus so that the use of supplementary nutrients has never been shown to be of value. However, some adjustment of pH is required; soda ash is used to maintain a pH of from 6.5 to 8.0.

The largest amount of waste comes from the use of barometric condensers on the vacuum jet systems. The company is installing surface intercondensers in place of the usual spray-type intercondensers on a number of the larger vacuum jets. It is expected that this not only will reduce the volume of waste from this source but also the total amount of organic material, since in the absence of the large volume of water much of the organic material may be separated and therefore recovered and disposed of by non-biological methods.

Aqueous wastes also result from various operations normal to chemical manufacturing processes, such as steam stripping, product washing, washing of tank cars or process tanks and equipment, etc.

Leaks, stuffing box losses of centrifugal pumps, floor washings, and accidental spills all add to the waste. A constant vigil must be kept on the waste sent to the treatment plant to spot and check on any unusual content. In addition, the source of all organic material discharged to the chemical sewer must be determined. These practices serve to keep the waste load at a minimum and, in addition, have served to save considerable sums by reducing losses. For example, it was found that at a large pump product losses through a leaking stuffing box totaled more than $50 per day. Use of a mechanical seal overcame this. In another instance increasing the condenser capacity of a still resulted in improved product yield equivalent to $10,000 per month in yield, and in addition reduced the B.O.D. content of the plant waste by more than 2,000 lb. per day.

All aqueous waste from the chemical sewer system is treated biologically by the use of trickling filters and impounding basins. At present, the daily waste volume averages 400 to 600 g.p.m.; the system has handled flows up to 1,200 g.p.m. The waste enters the toxicity basin and then flows to a settling basin, thence to the pumping station, from which it is sent to the No. 1 trickling filter. The waste in moving through the toxicity basin is retained, on the average, about 15 hr. before flowing into the settling basin. If there is an abnormal discharge from the plant which might be toxic to the filters, an effort is made to retain as much of this discharge as possible in the toxicity basin, and divert the feed, when the toxic discharge has passed, into the other basin. The toxic material in the toxicity basin is then gradually fed into the filter system by splitting the flow of raw waste between the two basins. When the material in the toxicity basin is sufficiently dilute so as to be no longer toxic, the flow is then di-

verted back to that basin exclusively. In addition, the inlet of the overflow pipe connecting the two basins is submerged to permit the toxicity basin to act as a skimming basin. Organic material which collects on the surface of this basin is burned periodically, usually every week or two.

It is possible to operate the filters in series or in parallel. However, they have always operated in series. Provision is being made to operate with either filter being first in line.

Treatment starts in the second basin, where the waste mixes with the recycle return from No. 1 filter. The No. 1 filter feed pump is operated at a fixed flow which is determined by the pump capacity; that is, the maximum flow possible is always pumped to the filter. This equals 8,400 g.p.m. for No. 1 pump. Forward flow from the No. 1 filter system to the intermediate basin is controlled by an adjustable weir in the flow splitter adjacent to No. 1 filter. Naturally, forward flow must equal that received from the plant. All material not sent forward is returned to the primary basin for recycle. Based on a 500-g.p.m. flow from the plant, the recycle ratio on No. 1 filter is 15.8 : 1.

The same cycle is repeated in No. 2 filter; again, the forward flow must equal that received from the plant. Since the pump for No. 2 filter has a capacity of only 3,600 g.p.m., at a feed of 500 g.p.m. the recycle ratio is 6.2 : 1. Forward flow from the No. 2 system enters the final sedimentation basin. From here waste overflows to No. 1 impounding basin, which is 34 acres in area. Further treatment of the waste after it leaves the filter system is discussed later.

Construction of Trickling Filters

The two trickling filters each measure 225 ft. in diameter at the base. The area of each filter is 31,400 sq. ft. and the stone is 5 ft. deep, giving a total volume of 5,800 cu. yd. of stone in each.

The flow splitter boxes are equipped with adjustable weirs, but it is planned to replace these weirs with controllers.

The pumps are protected by bar screens which serve to keep grass and weeds from fouling the pumps.

The concrete pad used as a base for the trickling filters is composed of 15 sections of reinforced concrete, each separated from the adjacent section by a copper expansion joint sealed with pitch. The slope is toward the center and equals 9 in. A tunnel runs through the center of each filter bed. This tunnel is high enough to permit a person to walk through. It serves to increase air circulation through the filter, permits easy inspection of the tile underdrains of the filter and, when necessary, has made flushing of this tile possible. The tile underdrains extend into the tunnel and all waste from the filter flows through this tunnel.

Special care was taken both in the selection of and in the placing of the trap rock on these filters. It was specified that clean, 3- to 4-in. rock be used and every effort was made to prevent classification during the installation.

Both No. 1 and No. 2 filters were originally constructed as intermediate rate filters. Pumping rates were fixed by the pump capacity as 3,600 g.p.m., which is equal to a hydraulic loading of 7.2 m.g.a.d. However, in June 1955 No. 1 filter was converted to high-rate operation and the pumping rate was raised to 8,400 g.p.m., or 16.8 m.g.a.d. It is expected that this increase in loading will result in better washing of the filter, thereby reducing the possibility that ponding might occur. In addition, better filter operation should result from the higher recycle ratios with its consequent increased dilution of the influent.

At the time of preparing this report, sufficient data have not been obtained to evaluate properly the effect of increased hydraulic loading. However, B.O.D. efficiencies above 95 per cent were obtained within two weeks after

putting No. 1 filter back into operation at the increased flow rate. This was in July, a time when high efficiency is normal.

Filter Operating Data

Because of the chemical structure of the waste treated at this plant, biological stabilization occurs more quickly than is the case with sanitary waste. However, the plant raw waste contains no settleable solids, therefore there is no primary sedimentation with its consequent reduction in the B.O.D. content of the raw waste. Consequently, all reported B.O.D. reductions were obtained across the filters.

Table I gives the efficiencies of both filters in terms of the load applied to each filter; that is, it shows the percentage of B.O.D. reduction on No. 1 filter in terms of the load applied to that filter and the same for No. 2. These data are monthly averages and therefore day-to-day variations in efficiency and the effect of system lags are smoothed out.

TABLE I.—Filter Efficiencies; Average Monthly Values

Month	B.O.D. Reduction[1] (%)		Average Mean Temp. (°F.)
	No. 1 Filter	No. 2 Filter	
1954			
July	82	63	79
Aug.	88	72	76
Sept.	85	91	71
Oct.	82	88	64
Nov.	60	88	48
Dec.	56	69	39
1955			
Jan.	56	65	34
Feb.	56	54	37
Mar.	59	65	45
Apr.	67	63	57
May	71	58[2]	65
June	—[3]	88	73
July	95	69	84

[1] Based on applied load.
[2] No. 2 filter down for four days for repairs.
[3] No. 1 filter out of service all month for conversion to high-rate operation.

TABLE II.—Filter Loading Versus Over-all Efficiency

Month	Raw Waste		Over-all B.O.D. Loading (lb./cu.yd./day)	Over-all B.O.D. Reduction (%)
	Avg. Vol. (g.p.m.)	B.O.D. (p.p.m.)		
1954				
July	900	850	1.52	95
Aug.	855	721	1.28	96
Sept.	382	1,430	1.31	99
Oct.	417	1,343	1.18	98
Nov.	420	1,570	1.38	96
Dec.	340	1,613	1.14	86
1955				
Jan.	376	2,040	1.60	85
Feb.	411	2,285	1.93	79
Mar.	504	2,135	2.22	86
Apr.	497	2,077	2.16	94
May	510	1,700	1.79	88[1]
June	492	1,358	1.41	88[1]
July	486	1,108	1.12	98

[1] Reduced efficiency because of filter shutdown.

The average mean temperatures at the Bristol plant are also shown in Table I. It is evident that No. 1 filter is strongly influenced by temperatures. The drop in activity shown for the winter months of 1954–55 duplicates a drop experienced on No. 1 filter in 1953–54. The earlier data are not shown. The volume of waste and the total B.O.D. handled per day by No. 1 filter has not varied too greatly over the year and although these factors do affect the efficiencies of these filters, they do not account for the cyclic variation noted in No. 1 filter. These variations probably result from the change in temperature.

The second filter is also affected by the temperature cycle, but to a lesser extent. B.O.D. loading of No. 2 filter is always far less than that of No. 1, since its feed is the effluent of No. 1. In summer months the waste applied to No. 2 filter is so dilute that the filter efficiency suffers. In winter months reduced efficiency of No. 1 causes heavier loading of No. 2. These factors tend

TABLE III.—B.O.D. Reduction Efficiency; Average Monthly Values

Month	B.O.D. Reduction[1] (%)			Filter Effluent B.O.D. (p.p.m.)
	No. 1	No. 2	Over-all	
1954				
July	82	13	95	48
Aug.	88	8	96	27
Sept.	85	14	99	23
Oct.	82	16	98	31
Nov.	60	36	96	78
Dec.	56	30	86	250
1955				
Jan.	56	29	85	316
Feb.	56	23	79	472
Mar.	59	27	86	306
Apr.	67	27	94	117
May	71	17[2]	88	208
June	—[3]	88	88	157
July	95	3	98	19

[1] Based on total load.
[2] No. 2 filter down for 4 days for repairs.
[3] No. 1 out of service all month for conversion to high-rate operation.

to obscure the cyclic trend in the efficiency of No. 2 filter.

Table II gives both the volumetric and B.O.D. loading of the treatment plant and the over-all efficiency obtained. A study of this table shows that both loading and the volume of waste sent to the filter has been subject to considerable variation. However, air temperature appears to determine filter efficiency to the greatest extent.

In Table III the B.O.D. reduction based on the original raw waste sent to the filter is given. The fourth column shows the over-all efficiency obtained and the last column shows the B.O.D. content of the plant effluent discharged to the impounding basin. The quality of this effluent determines the condition of the impounding basin, since if this basin is overloaded its ability to maintain aerobic conditions may be exceeded and it will become septic.

The advantage of the second-stage filter becomes evident in the winter months. Although the activity of No. 2 filter in terms of percentage reduction of the load applied to it may show a characteristic drop in colder weather, reduced activity on the part of No. 1 filter results in a heavier applied loading to No. 2 filter causing it to stabilize more B.O.D. in cold weather than in hot in spite of its reduced activity. This is seen in the column showing the net per cent reduction of the over-all or total applied load to the entire system. As the pounds of B.O.D. reduced in No. 1 filter drops, that of No. 2 filter rises. It may be said that in the winter No. 2 filter takes over and completes the job.

No. 2 filter also takes over in times of stress. Shock loads resulting from high organic loading, or from high concentrations of acids or bases, or from concentrations of materials toxic to biological processes, have been sent to the filter. This may result from accidents, or from the need for quick departmental shutdowns to make repairs, or from the need to dispose of waste material. As previously noted, the waste treatment facilities serve to guard the Delaware River from hazards of this type.

It has been found that even though the activity of No. 1 filter may fall off almost to zero under the influence of some shocks, the complete recovery of the filter is only a matter of two to four days. No seeding has been found necessary to obtain this rapid recovery. In addition, although the effect may be very great on No. 1 filter, the first filter serves to blunt the shock or destroy enough of the material so that when the waste reaches No. 2 filter satisfactory stabilization is obtained. This is, again, an instance in which No. 2 filter takes over and completes the job when the effectiveness of No. 1 is reduced.

It has also been found that even after a shutdown lasting almost a month a filter will become almost fully active within four days after start-up. The rapid recovery of operating efficiency of these filters and their relative

nonsensitivity to stress have contributed greatly to the ease of operation .

Impounding Operation

The effluent from the filters is discharged to a 34-acre impounding basin, called basin No. 1. Here its retention time averages from one to two months, depending upon rain or the volume of plant effluent. During this period there is a further reduction in the B.O.D. of the waste and an improvement in its color. An average of about 150 g.p.m. of this waste is lost in basin No. 1 through evaporation and percolation. However, in time, the level of basin No. 1 rises so that it is necessary to discharge waste held in this basin. At this point it is pumped to basins Nos. 2 and 3, which total 22 acres. While making this transfer the waste is intensively chlorinated, usually at about 400 p.p.m. Chlorination at this level destroys the biological life and any residual B.O.D. of the waste. It also serves to remove any residual taste. The resulting effluent usually has a B.O.D. and taste threshold of 10 or less.

The chlorinated waste is stored until all residual chlorine has left, then permission is requested of the Pennsylvania State Regional Engineer to discharge this waste to the river. The rate of this discharge is limited so as not to exceed 1,000 g.p.m.

To sum up, waste is first treated biologically on two filters operating in series, then impounded for further B.O.D. reduction, then chlorinated intensively, and finally discharged to the river. Altogether, this treatment system includes a tremendous factor of safety which serves to protect the river and results in a clean waste free from tastes and odors.

Reference

1. Majewski, F. M., Proc. of 8th Indus. Waste Conf., Purdue Univ., 328 (1953).

GROUP FLIGHT FORMING FOR LOS ANGELES MEETING

Arrangements are being made by members of the New Jersey Sewage and Industrial Wastes Association to form a group flight to the Los Angeles Meeting. Present plans anticipate the use of the American Airlines "Royal Coachman" leaving New York on Friday, Oct. 5 at 9:30 AM and arriving in Los Angeles at 3 PM. On the return trip the group will leave Los Angeles on Friday, Oct. 12 at 8:30 AM and will arrive in New York at 7:15 PM.

The fare for this travel is $99 each way, plus 10% Federal Tax. Lunch will be served enroute at a cost of $1.25.

Anyone interested may secure further information by writing to Mr. Sol Seid, Chief Engineer, Department of Public Works, 261 Sandford St., New Brunswick, N. J., or to Mr. Henry Van Der Vliet, Superintendent, Joint Meeting Rutherford, East Rutherford and Carlstad, P. O. Box 281, Rutherford, N. J.

Make your final arrangements to attend now!

CONTROL OF SLUDGE VOLUMES FOLLOWING LIME NEUTRALIZATION OF ACID WASTES*†

By S. D. Faust, H. E. Orford, and W. A. Parsons

Rutgers University, New Brunswick, N. J.

Lime neutralization of waste sulfuric acid solutions is one of the oldest and perhaps the most prevalent of all industrial waste treatment processes. A major disadvantage of the process is the handling and disposal of sludge produced as a reaction product. The problem is aggravated when lagooning, the most economical method of disposal, is impractical because of esthetic considerations, or if limited land area is available.

Through the years numerous studies have been made of the lime neutralization process with the objective of finding practical methods of obtaining sludges that settled rapidly and could be dewatered easily on vacuum filters or centrifuges. The more attractive of the methods developed, such as those of Heise (1), Hoak (2), and Wing (3), were intended for application to concentrated acid solutions containing iron salts. They are not suited for general application to low concentration—high volume wastes because the processes require overtreatment or high temperatures.

Dilute sulfuric acid wastes, typified by mine drainage, wash waters from pickling operations, and process waters from chemical, munitions and titanium industries, are on an equivalent basis the principal component of acid waste discharge. Although less reaction product is formed during lime neutralization of a ton of dilute waste acid than with a ton of concentrated waste acid, the volume of sludge formed may be greater because there is a tendency for sludges from dilute wastes to have a high specific volume. Some preliminary investigation indicated that lime-sulfuric acid sludges could be concentrated by addition of seed crystals. The objective of this study was to systematically investigate crystal seeding as a means of concentrating sludges formed from lime neutralization of sulfuric acid wastes.

Methods of Study

Experiments were conducted on a half-liter scale in which sulfuric acid solution containing various dosages of native gypsum powder or return sludge were neutralized by addition of 10 per cent lime slurry. Agitation necessary to promote the reaction in a 6-min. reaction period was supplied by an electric mixer running at 400 r.p.m. The pH value of the lime-acid mixture was determined continuously during the reaction period with an electric pH meter. Following the reaction period, the neutralized mixture was transferred to a 1-l. graduated cylinder for determination of sludge settling characteristics. The volume of sludge was recorded at 0, 1, and 24 hr. When the 24-hr. value for sludge volume had been obtained, the sludge was resuspended, and the suspended solids of the neutral mixture were determined.

Suspended solids, iron, aluminum, and acidity were determined in accord with "Standard Methods" (4). Sul-

* Paper of the Journal Series, New Jersey Agricultural Experiment Station, Rutgers University.

† Presented at 1955 Annual Meeting, Pennsylvania Sewage and Industrial Wastes Assn.; State College, Pa.; Aug. 22–24, 1955.

TABLE I.—Effect of Gypsum Addition on Characteristics of Sludge Resulting from High-Calcium Quicklime Neutralization of Two Per Cent Sulfuric Acid [1]

(1) Gypsum Dosage (p.p.m.)	(2) pH at 6 Min.	(3) Sludge Volume (ml.) At 0 Hr.	(4) Sludge Volume (ml.) At 1 Hr.	(5) Sl. Vol. at 1 Hr. (% of control)	(6) Susp. Sol. in Neut. Mix. (%)	(7) Sludge Susp. Sol. at 1 Hr. (%)
0[2]	12.1	555	250	100	2.5	5.6
5,000	11.4	550	170	68	3.0	9.8
15,000	11.6	550	108	43	3.6	18.1
30,000	11.8	560	110	44	4.9	25.0
45,000	11.6	560	120	48	6.0	28.0
60,000	11.7	565	138	55	7.0	28.6
75,000	11.6	570	150	60	8.1	30.6

[1] Acid sample = 500 ml.; lime added = 6.1 gm. CaO per 500 ml. of acid; temperature = 25° C.; precipitated sludge = 14.0 gm.
[2] Control.

fate was determined by an amperometric titration in accord with the method of Kolthoff and Pan (5).

Materials

The high-calcium quicklime is of the commercial type, composed of approximately 95 per cent CaO and 5 per cent impurities. The dolomitic quicklime is also of the commercial type, being composed of calcium and magnesium oxides containing less than 5 per cent impurities and with MgO fraction constituting 35 to 45 per cent of the total. Both quicklimes were slaked before introduction to the acid with distilled water at a temperature of 95° to 100° C. The slurries were allowed to reach room temperature before use.

The acid solution was synthetically prepared from sulfuric acid and distilled water. A stock solution of standard normality was prepared and the lesser concentrations prepared by dilution.

The gypsum was supplied as commercial Terra Alba, which is 97.8 per cent $CaSO_4 \cdot 2H_2O$. It is a finely ground powder derived from the native gypsum rocks.

The industrial waste samples were supplied by the companies whose names appear later in the paper.

Recycling of Native Gypsum

Effect of Gypsum Seeding Upon Sludge Characteristics

Several experiments were conducted to examine the effect of gypsum addition upon sludge characteristics resulting from the lime neutralization of sulfuric acid. The acid concentrations ranged from 1 to 10 per cent by weight. Both high-calcium and dolomitic quicklimes were used in the experiments. The results from a typical test are shown in Tables I and II and Figures 1 and 2 for the neutralization of 2 per cent sulfuric acid.

Since the effect of gypsum on sludge volume reduction is similar for both high-calcium and dolomitic limes, the discussion is limited to the high-calcium results. The same generalizations can be drawn for both systems.

From Table I, Columns 4 and 5, it can be observed that as the gypsum dosage increased, there was a significant decrease in sludge volume after 1-hr. settling from the control where no gypsum was used. This decrease in sludge volume reached a maximum. Beyond this point, the sludge volume reduction became less significant. In Column 5, the sludge volumes are expressed as per cent of the control for easy comparison. One must subtract the value in Column 5 from 100 in

TABLE II.—Effect of Gypsum Addition on Characteristics of Sludge Resulting from Dolomitic Quicklime Neutralization of Two Per Cent Sulfuric Acid [1]

(1) Gypsum Dosage (p.p.m.)	(2) pH		(3) (4) Sludge Volume (ml.)		(5) Sl. Vol. at 1 Hr. (% of control)	(6) Susp. Sol. in Neut. Mix. (%)	(7) Sludge Susp. Sol. at 1 Hr. (%)
	At 6 Min.	At 1 Hr.	0 Hr.	1 Hr.			
0[2]	3.9	4.6	540	182	100	1.24	3.62
4,000	3.7	3.9	540	160	88	1.61	5.45
10,000	3.8	4.0	545	50	28	1.98	21.6
15,000	3.7	4.0	540	48	26	2.42	27.3
30,000	5.1	5.5	550	50	28	3.34	36.8
45,000	5.8	6.2	550	70	39	4.56	35.9

[1] Acid sample = 500 ml.; lime added = 5.2 gm. CaO·MgO per 500 ml. of acid; temperature = 25° C.; precipitated sludge = 6.6 gm.
[2] Control.

order to obtain per cent sludge volume reduction. As expected, the increase in per cent sludge volume reduction reached a maximum and then decreased as excess gypsum dosages were applied.

The sludge solids concentrations resulting from the various gypsum additions after 1-hr. settling are given in Column 7. For the smaller additions, the per cent solids rapidly increased with increased dosages until a point of maximum concentration was reached.

In Figures 1 and 2, the data from Tables I and II, Columns 5 and 7, are plotted *versus* gypsum dosage. The range of optimum gypsum dosage becomes clear for the lime-acid systems presented. Similar curves were obtained at other acid concentrations.

Effect of Gypsum Addition on Sludge Settling Rates

Tables III and IV present data to show the effect on the rate of sludge settling when gypsum is added. The gypsum dosages shown are selected from the optimum range where the maximum effect is recorded. A general observation can be made that unseeded sludges require 1 hr. to reach their final volumes, whereas the seeded sludges conclude their sedimentation within 15 min.

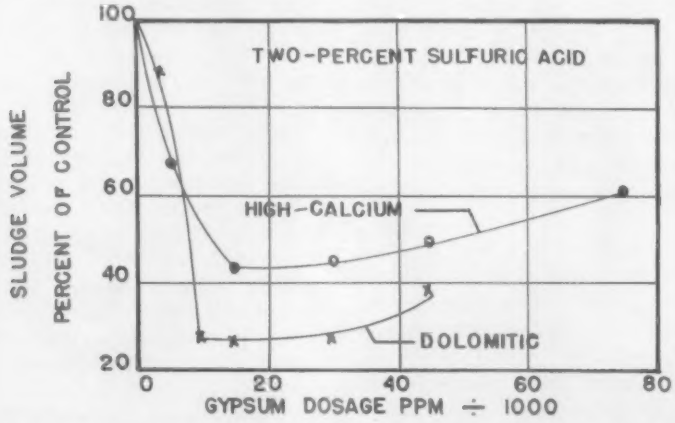

FIGURE 1.—Effect of gypsum addition on sludge volumes after 1 hr. of settling.

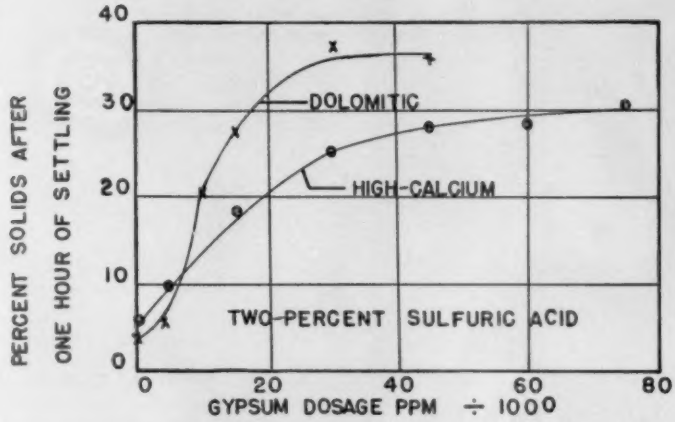

FIGURE 2.—Effect of gypsum addition on sludge suspended solids.

Effect of Acid Concentration on Optimum Gypsum Addition

Figure 3 shows the effect of acid concentration on the optimum gypsum dosage. These dosages were selected from the range where gypsum showed its maximum effect for each acid-lime system studied.

From the high-calcium quicklime-acid systems the following observations can be made:

1. The optimum gypsum dosage increases with an increase in acid concentration.
2. The increase results in a linear curve.
3. Beyond an acid concentration of 5 per cent, the range of optimum gypsum dosage becomes less pronounced.

Similar observations can be made for the dolomitic quicklime-acid systems. The linear curve falls below the high-calcium curve and is indicative of lower optimum gypsum dosages for the same acid concentrations. An optimum range can be distinguished up to an acid concentration of 10 per cent.

Effect of pH on Gypsum Dosage

The effect of pH on gypsum addition was studied by (a) overneutralization to a pH beyond 8.0, and (b) underneutralization to pH 4.0. This factor was investigated for the purpose of learning whether or not any advantage might be gained by neutralizing to a pH of 4.0 and seeding the sludge with gypsum.

TABLE III.—Effect of Gypsum Addition on Settling Rates of Sludge Resulting from High-Calcium Quicklime Neutralization of Sulfuric Acid

Acid Conc. (p.p.m.)	Gypsum Dosage (p.p.m.)	Sludge Volume (ml.)				
		0 Hr.	15 Min.	30 Min.	1 Hr.	24 Hr.
10,000	—	525	170	160	160	150
10,000	10,000	530	55	55	55	55
20,000	—	555	260	250	250	223
20,000	15,000	550	110	110	108	108
50,000	—	625	472	468	450	430
50,000	30,000	630	245	245	245	230

TABLE IV.—Effect of Gypsum Addition on Settling Rates of Sludge Resulting from Dolomitic Quicklime Neutralization of Sulfuric Acid

Acid Conc. (p.p.m.)	Gypsum Dosage (p.p.m.)	Sludge Volume (ml.)				
		0 Hr.	15 Min.	30 Min.	1 Hr.	24 Hr.
10,000	—	520	90	88	80	60
10,000	4,000	525	25	25	25	25
20,000	—	540	375	205	182	150
20,000	10,000	540	50	50	50	42
50,000	—	610	580	520	400	320
50,000	30,000	620	200	160	158	150
100,000	—	760	700	600	490	445
100,000	60,000	770	545	360	250	240

The systems studied were as follows:

1. High-calcium quicklime-2 per cent sulfuric acid.
2. Dolomitic quicklime-2 per cent sulfuric acid.

Results

Results of the experimental work brought forth the following general observations:

1. Introduction of gypsum into the acid-lime systems produces the same effects on the sludge characteristics at a pH of 4.0 as recorded at a pH of 8.0 or greater. This provides experimental verification for the earlier studies.
2. The curves show a sharper inflection at the point of maximum sludge volume reduction.
3. The sludge suspended solids remained at the same concentration levels.

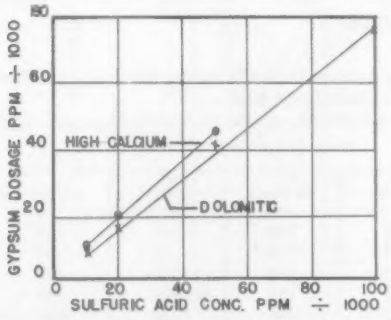

FIGURE 3.—Effect of acid concentration on gypsum dosage.

4. The optimum gypsum dosages were not lowered, but remained the same.

Recycling of a Gypsum-Seeded Sludge

A series of experiments was conducted to investigate the possibility of returning a sludge capable of producing much the same effect as the native gypsum. It was desired to acquire a sludge whose own characteristics in regard to settleability and solids concentration were optimum. This was accomplished by selecting an acid concentration, adding its optimum gypsum dosage, neutralizing, settling, and recycling this sludge back to the same acid concentration.

Both high-calcium and dolomitic quicklime neutralization of 2 per cent sulfuric acid were studied. The return sludge for the high-calcium quicklime study was seeded with a gypsum dosage of 20,000 p.p.m., which resulted in a suspended solids concentration of 18.6 per cent. For the dolomitic study, a return sludge seeded with 10,000 p.p.m. gypsum and a suspended solids content of 19.8 per cent was employed.

The effect of returning a gypsum seeded sludge on the sludge suspended solids is shown in Figure 4. From the high-calcium quicklime system, it is observed that the solids concentration reaches a maximum value of approximately 18 per cent. The dolomitic quicklime data indicate that the

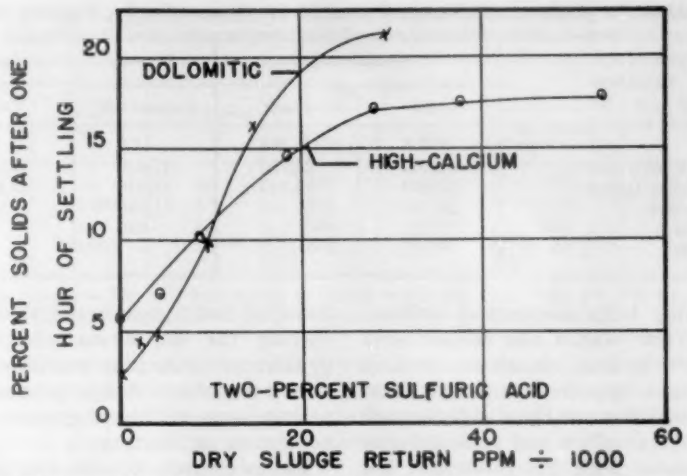

FIGURE 4.—Effect of a gypsum-seeded sludge return on sludge suspended solids.

maximum solids concentration is being approached.

Recycle Sludge Return Process

Two series of experiments were made in which iron-sulfuric acid waste from National Lead Company (Table V) was neutralized with high-calcium quicklime in a recycle sludge return process. These experiments commenced with comparable neutralization of two 500-ml. samples of acid solution to pH 10.5, one containing 10 gm. of native gypsum powder, the other no seed crystals. Each of these samples served as a starter for a series of sludge return experiments in which the sludge from the previous experiment (minus a small sample removed for determination of suspended solids) was recycled (transferred) to the acid sample of the subsequent neutralization experiment made on another day. In both series of experiments, the dry weight of sludge solids returned to each subsequent experiment increased progressively with continued recycling.

The results of the recycle sludge return experiments, condensed in Figure 5, showed the sludge suspended solids concentration of both gypsum-seeded sludges and sludge with no gypsum added to converge towards a value of 14 per cent after 12 recycles of sludge return. The suspended solids concentration of the gypsum-seeded sludges decreased from 17.5 per cent to 14 per cent with continued recycling, whereas the unseeded sludges increased in suspended solids concentration from 4.3 per cent to 14 per cent. In the seeded and unseeded experiments the dry weight of sludge solids returned to the process for the twelfth recycle was approximately 115,000 p.p.m.

The results of other experiments with the recycle sludge return process using 2 per cent pure sulfuric acid and high-calcium quicklime were similar to the data presented for the iron-sulfuric acid waste. The 1-hr. suspended solids concentration of the seeded and unseeded sludges again converged to a value of about 14 per cent in 9 recycles of sludge return and the dry weight of the sludge solids returned at the ninth recycle was approximately 125,000 p.p.m.

Addition of Gypsum to Wastes Containing Sulfuric Acid

It was desired to obtain data from the application of the proposed return gypsum process to industrial wastes

TABLE V.—Analyses of Industrial Wastes Used in Gypsum-Seeding Experiments

Constituent	Pharmaceutical		Titanium	Chem. Mfr.
	Ciba	Merck	National Lead	Calco
pH	0.5	0.7	1.0	1.0
Mineral acidity (p.p.m.)	30,100	24,750	12,430	12,350
Total acidity (p.p.m.)	31,000	26,150	13,310	12,850
SO_4 (p.p.m.)	28.400	21,110	11,350	10,250
Fe (p.p.m.)	55	6	660	12
Al (p.p.m.)	15	7	—	35

containing large amounts of sulfuric acid. These wastes also contain such materials as iron, aluminum, organic acids, and organic compounds that would contribute to the sludge through lime neutralization and constitute an interference with the process. Analyses of these wastes are given in Table V.

The experimental results from high-calcium and dolomitic quicklime neutralizations are recorded in Tables VI and VII. The data indicate that in all four systems the addition of native gypsum is successful in reducing sludge volume and concentrating the solids. The dosages shown in the tables are not necessarily optimum, but they are selected as nearly optimum from the various amounts studied.

Discussion

Sludge volumes resulting from lime neutralization of dilute sulfuric acid wastes can be controlled by gypsum-seeding techniques. However, it is doubtful that a commercial process involving the continuous addition of gypsum powder alone would be practical. A return sludge process with perhaps some additional gypsum would seem more satisfactory.

Native gypsum powder was used in the initial experiments for simplification and greater laboratory control of applied dosages. The results are of theoretical interest because subsequent experimentation with return sludges is more easily evaluated.

The mechanism involved in the concentration of sludge effected by addition of return sludge or gypsum crystals has not been established, but the process is conceived of as a deposition of reaction products on seed crystals. If sludge concentration by sludge return is examined as a crystal seed process, the objective will be production on neutralization of a sludge with the best settling characteristics. The best settling sludge would usually be the one with the largest mean particle

TABLE VI.—Effect of Gypsum Addition on Characteristics of Sludge Resulting from High-Calcium Quicklime Neutralization of Industrial Wastes Containing Sulfuric Acid [1]

Waste	Gypsum Dosage (p.p.m.)	pH at 6 Min.	Sludge Volume (ml.)			Susp. Sol. at 1 Hr. (%)
			0 Hr.	1 Hr.	Per Cent of Control at 1 Hr.	
National Lead	—	10.8	540	192	100	5.57
	10,000	11.1	545	120	63	12.7
Calco	—	10.2	540	120	100	6.7
	10,000	10.1	540	75	58	18.1

[1] Waste sample = 500 ml.; lime added to National Lead = 4.1 gm. CaO per sample; lime added to Calco = 3.9 gm. per sample; temperature = 28° C.

TABLE VII.—Effect of Gypsum Addition on Characteristics of Sludge Resulting from Dolomitic Quicklime Neutralization of Industrial Wastes Containing Sulfuric Acid [1]

Waste	Gypsum Dosage (p.p.m.)	pH at 6 Min.	Sludge Volume (ml.)			Susp. Sol. at 1 Hr. (%)
			0 Hr.	1 Hr.	Per Cent of Control at 1 Hr.	
Merck	—	4.0	560	140	100	6.4
Merck	12,000	4.7	565	68	49	22
Ciba	—	4.8	565	200	100	5.4
Ciba	12,000	5.8	575	90	45	19.1

[1] Waste sample = 500 ml.; lime added to Merck = 6.5 gm. CaO·MgO per 500 ml. acid; lime added to Ciba = 7.77 gm. CaO·MgO per 500 ml. acid; temperature = 32° C.

size. Hence, it would seem desirable to add just a few seed crystals so that when the reaction products are deposited they will grow large in size and be easily settleable. Unfortunately, it appears that freshly precipitated calcium sulfate makes a poor crystal seed surface for additional calcium sulfate deposition. Consequently, deposition will occur only on the original surface of the seed crystals. Therefore, a large crystal seed dosage must be employed if an appreciable amount of the reaction product is going to be deposited. It follows that the greater the surface-to-volume ratio of crystals with comparable seeding properties, the less the required dosage to receive the reaction products; and conversely, the more reaction products, the greater the required seed crystal dosage. This has been verified experimentally (Figure 3) because it was noticed that the higher the acid concentration, the larger the seed crystal dosage.

Native gypsum powder represents a dense and rapid settling form of calcium sulfate crystal, probably as a result of an infinite aging period. Thus, on an equivalent weight basis, native gypsum would allow greater deposition and crystal growth than a freshly precipitated calcium sulfate sludge. This is verified experimentally (Figure 2) where it is shown that a sludge seeded with 30,000 p.p.m. of gypsum acquires a solids concentration of 25 per cent, whereas the same sludge seeded with 125,000 p.p.m. of freshly precipitated calcium sulfate acquires a solids concentration of 14 per cent.

Per cent sludge suspended solids is an expression that can be used to compare sludges resulting from neutralization of various acid solutions with either high-calcium or dolomitic limes. It is also a good parameter to evaluate a sludge return process. Since the expression is a weight-per-volume unit, it compensates for different amounts of sludge produced from different neutralizations. Thus, an increase in suspended solids will mean that a relative sludge volume reduction is occurring. For example, if a sludge whose initial solids concentration is 2 per cent could be compacted to a solids concentration of 10 per cent, this would result in a relative sludge volume reduction of 80 per cent.

The usefulness of this expression is verified by reference to Table I, Columns 5 and 7. There is a significant increase in solids concentration at a gypsum dosage of 45,000 p.p.m. over the solids concentration at 15,000 p.p.m. This is true despite the apparent increase in sludge volume from 108 ml. to 120 ml. Beyond the 45,000-p.p.m. gypsum dosage, the sludge suspended solids curve levels off, indicating maximum solids concentration and sludge volume reduction occurring at this level. It follows that the optimum

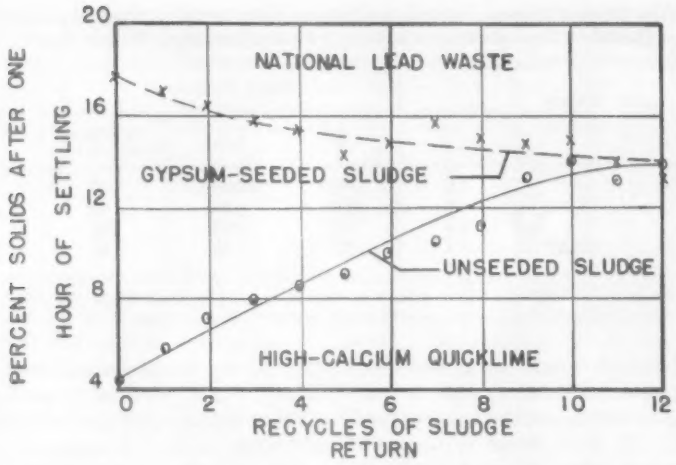

FIGURE 5.—Effect of recycle sludge return on sludge suspended solids.

gypsum dosage for concentration of sludge from this acid-lime system is approximately 45,000 p.p.m.

From the various sludge return experiments, it is evident that an increase in seed crystal dosage produces a significant increase in sludge solids concentration until a maximum concentration is reached. Additional seed crystal dosage beyond the first point of maximum solids concentration is unnecessary. Therefore, it is reasonable to assume that the optimum sludge return dosage occurs at this point. The experimental data indicate that the optimum dosage appears to range from one to three times the weight of calcium sulfate on neutralization, depending on the properties of the seed crystals employed.

The processes are apparently unaffected by impurities commonly present in waste sulfuric acid solutions (Figure 5 and Tables VI and VII). The impurities, such as iron, aluminum, organic acids, organic compounds, would contribute to the sludge through lime neutralization and constitute an interference. However, the resultant sludges are effectively controlled by gypsum-seeding techniques.

Conclusions

1. Sludges resulting from lime neutralization of sulfuric acid solutions can be concentrated by addition of gypsum or return sludge to the acid before neutralization.

2. The processes presented are apparently unaffected by impurities commonly present in waste sulfuric acid solutions.

3. The optimum sludge return dosage appears to be one to three times the weight of the calcium sulfate formed from the neutralization reaction.

4. The resultant concentration of the sludge is dependent upon the properties of the seed crystals and the quantity added.

Summary

A series of laboratory experiments was conducted to examine sludge return processes for control of sludge volumes resulting from the high-calcium and dolomitic lime neutralization of waste sulfuric acid solutions.

Three processes are presented, as follows:

1. Addition of native gypsum powder.
2. Return of a sludge initially seeded with gypsum.
3. Return of unseeded sludge.

Acknowledgment

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DISCUSSION

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The authors have reported that addition of calcium sulfate crystals, either in the form of gypsum powder or sludge, to sulfuric acid wastes prior to neutralization with lime provides a significant reduction in sludge volume. This was true for sulfuric acid-water systems ranging from 1 to 10 per cent acid, and for the four industrial waste samples tested. This, as far as can be determined, is the first approach to control of sludge volume by either seeding or return sludge techniques, although both have been used in other fields for some time. This paper, therefore, is a valuable contribution to the field.

It is noted that the authors have used "per cent sludge suspended solids" as a means of evaluating results. Since the purpose is to produce the minimum volume of sludge for a given waste, sludge volume should be the basis of evaluation. In the example cited by the authors to substantiate their choice, 15,000 p.p.m. of gypsum gave a sludge volume of 108 ml. containing 18.1 per cent solids, whereas 45,000 p.p.m. of gypsum gave 120 ml. of sludge containing 28 per cent solids. If sludge volume is used as the parameter, 15,000 p.p.m. of gypsum is the optimum dosage, giving 108 ml. of sludge to dispose of instead of 120 ml., thereby realizing a saving of 30,000 p.p.m. of gypsum. This is obviously a much more desirable condition than exists under the per cent sludge suspended solids parameter chosen by the authors.

In batch work where sludge is returned, the incremental increase in volume of sludge from batch to batch would be used to determine the optimum amount of returned sludge, the optimum being the amount above which no decrease in incremental volume occurs.

The mechanism of sludge concentration outlined appears to be sound. However, it has been noted that calcium sulfate (or gypsum) tends to adhere to almost all suspended solids present in the waste stream. While this may be peculiar to the wastes of a rayon plant, it does suggest the possibility that some locally available material might also be used.

From the data in Table III it is noted that the per cent reduction in sludge volume decreases as acid concentration increases in the range of 1

to 5 per cent acid neutralized by high-calcium lime. In Table IV a similar situation exists in the range of 2 to 10 per cent acid using dolomitic lime. However, the percentage reduction in the 24-hr. sludge volume for the 1 per cent acid neutralized by dolomitic lime is 59 per cent, as compared to 72 per cent for 2 per cent acid. This offers support to the authors' statement that sludges from neutralization of dilute acids tend to have high specific volumes.

The percentage sludge volume reduction on the industrial wastes from National Lead and Calco reported in Table VI are much less than would be expected from results on neutralization obtained on the 1 per cent acid solution in Table III; 63 and 58 per cent as compared to 31 per cent for the 1 per cent acid. This, coupled with the fact that the percentage sludge volume reduction was approximately the same for both wastes in spite of the great difference in contaminating constituents, suggests the possibility that some seeding by suspended matter in the control sample might have occurred. The same effect is also evident for the wastes reported in Table VII, but to a lesser degree.

Summary

The authors have presented information which, if used, will provide a significant reduction in the volume of sludge resulting from neutralization of sulfuric acid wastes. The amount of reduction possible will depend on such factors as acid concentration, amount and nature of contaminants that are also precipitated, and possibly the amount of suspended solids present. A study of each waste will be required to determine optimum amounts of gypsum or returned sludge to be used.

DISASTER PLANNING

The importance of restoring water and sewage utilities following enemy attacks upon American cities and towns, or after national disasters, is described in a new blooklet, "Emergency and Disaster Planning for the Water and Sewerage Utilities," published by the Business and Defense Services Administration, U. S. Department of Commerce. It offers the recommendations of well-known authorities in the sanitary engineering field on measures which should be taken as quickly as possible after disaster strikes.

Emphasis is placed on establishing, in advance, mutual aid agreements and arrangements with adjacent water and sewage utility managements. The establishment of channels of authority in collaboration with local, state, and federal civil defense organizations is recommended, in order to assure continuity of operation. Also stressed is the importance of planning by each utility for storage of records, materials, and equipment—all vitally needed to restore service following a disaster. Suggestion is made that, through a supervising engineer chosen to coordinate state or regional activities, information be exchanged by utilities. Sample forms for reporting these data, and a list of reference material pertinent to emergency planning, are included.

Copies of this booklet may be purchased from the Office of Administrative Operations, U. S. Department of Commerce, Washington 25, D. C., for 20 cents.

STUDIES OF PIGMENTED NON-SULFUR PURPLE BACTERIA IN RELATION TO CANNERY WASTE LAGOON ODORS *

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Prolific growth of certain pigmented bacteria occurs in several Minnesota canning waste lagoons and appears to be accompanied by periods of reduced odor offensiveness. It has been suggested that these organisms might provide a biological means to effect control of lagoon odors. On the basis of this suggested relationship a study was initiated to evaluate the feasibility of using these organisms in controlling or reducing lagoon odors.

In this evaluation, a fundamental problem appeared to be the establishment of an early growth of the bacteria in the lagoons at the time when odors are normally most offensive. The appearance of the organisms in a lagoon was generally later in the season when improved odors would be expected, and the possibility of a causal relationship between their growth and the reported improvement in odors was uncertain.

The first occurrence of these pigmented bacteria to come to the attention of the Minnesota Department of Health was in 1947 in a cannery waste lagoon at Fairmont, Minn. Reddish growths of these organisms have since been noted in a number of vegetable cannery waste lagoons in the state. At least one lagoon inoculated from another lagoon red with these bacteria has been reported to have produced heavy growths with decided improvement in odor.

In this study information was obtained on the identification, isolation, and subsequent growth of the bacteria in pure culture; preliminary laboratory studies of the bacteria in decomposing corn waste; and field studies of the bacteria in pea and corn cannery wastes in test lagoons.

Identification and Isolation of the Organisms

The identification and isolation of the organisms responsible for the red coloration of the lagoons was undertaken in 1949 on samples collected from the cannery waste lagoon at Waseca, Minn. These samples were deep rose in color and upon microscopic examination were found to contain large numbers of bacteria morphologically similar to the sulfur purple bacteria *Rhodothece pendens* Molisch, although no sulfur globules typical of this group were clearly visible within the cells. Since this pigmented type appeared to predominate in such numbers as to constitute an almost pure culture, 18 l. were concentrated to obtain sufficient cell material for detailed spectroscopic analysis of the pigments and for analysis for the presence of sulfur.

In the spectroscopic analysis, extractions of the centrifuged cell materials with 95 per cent ethyl alcohol removed a bright green pigment and chloroform removed a red pigment. The maximum absorption of the green extract was found at 775 mμ and three absorption maxima at 480, 505, and

* A condensation of a comprehensive report on this study by Duane E. Cozart, former Public Health Biologist with the Minnesota Department of Health, and Bernard R. Jones.

540 mμ of wave length were found in the red extract. The absorption maximum of 775 mμ for the green alcoholic extract agreed closely with the value of 774 mμ given by Van Niel (1) for alcoholic extracts of the pigment of non-living cells of purple bacteria. The maxima obtained for the red pigment agree closely with the values (479, 506 and 540 mμ) given for spirilloxanthin, a pigment found in various members of the purple bacteria and which has been reported from at least two species of non-sulfur purple bacteria (1).

In the analysis for sulfur, expected to be present in the sulfur purple bacteria, a sample of the cell mass gave negative results when extracted with carbon disulfide and examined microscopically for sulfur particles. Oxidation of the examined residue with nitric acid and bromine followed by treatment with barium sulfate also produced no detectable precipitate of barium sulfate. It was concluded that no significant amount of elemental sulfur had been removed by the carbon disulfide.

To detect forms of sulfur not soluble in carbon disulfide, a portion of the cell mass was subjected in triplicate to oxidation by sodium carbonate-sodium peroxide fusion and treated with barium chloride. The resulting precipitate weighed as barium sulfate contained a calculated 0.37 per cent sulfur that was present in the original dry cell material. Since this amount could be accounted for by the organic or protein sulfur alone, it was concluded that there was no significant amount of elemental sulfur present.

The agreement between absorption maxima and the absence of a significant quantity of free sulfur strongly indicated the bacteria in question belonged to the non-sulfur purple bacteria (*Athiorhodaceae*).* However, since sulfur globules reportedly may not be found in the sulfur purple bacteria under certain conditions, the final separation of the two groups rested upon the ability of the sulfur purple group to develop autotrophically in simple inorganic media (the non-sulfur group generally requires organic sources of carbon and complex growth factors). Therefore, crude enrichment cultures of the organisms were set up to substantiate the identification of the group on the basis of biochemical and cultural characteristics, as well as to isolate the various species. Media for these cultures were selected on the basis of the preliminary indications that the organisms were non-sulfur purple bacteria.

Laboratory cultures were inoculated from samples of water from waste lagoons at Waseca and Glencoe, Minn., which showed evidence of growth of the pigmented organisms. For these cultures the following basal sterile medium was used: 1.0 g. $(NH_4)_2$ SO_4, 0.2 g. $MgCl_2$, 3.0 g. $NaHCO_3$, 0.05 g. Na_2S, 0.1 g. yeast autolysate, and 30 ml. of 1.5M phosphate buffer per liter of distilled water. The $NaHCO_3$ and Na_2S were autoclaved separately. For initial cultures one set of the basal medium was furnished an organic supplement by the addition of 0.2 per cent of ethyl alcohol, and a second set by the addition of 0.2 per cent of sodium propionate. With the pH adjusted to 7.0, the two sets of media were placed in glass-stoppered bottles, inoculated with 0.5 ml. of raw sample, and incubated at room temperature under continuous illumination. Growth, as indicated by a reddish color, developed in the fortified crude cultures, but not in the control.

To further test the possibility that the pigmented growth thus obtained

* The photosynthetic non-sulfur purple bacteria are known to use light principally in the infrared and near-infrared region of the spectrum. They are heterotrophic facultative anaerobes which use a number of organic substances, including alcohols and organic acids, and certain oxidizable inorganic substances as substrates, and require in addition one or more growth factors supplied in the laboratory by yeast extract.

might be due to sulfur purple bacteria instead of non-sulfur purple bacteria, inoculum from the crude cultures was transferred into basal medium containing no supplementary organic material or yeast autolysate. Despite repeated attempts, no growth was obtained in this medium, which presumably was suitable to the sulfur purple group but lacked the organic carbon and growth factor requirements of the non-sulfur purple group.

The apparent absence of free sulfur in the cells, and lack of growth in a medium containing sulfide but no source of organic nutrients, were considered sufficient evidence that the bacteria in question belonged to the non-sulfur purple group. By microscopic examination it had been previously noted that the forms present in the lagoon samples were similar to those of the genus *Rhodopseudomonas* as described by Van Niel (1).

Isolation of various species of the genus *Rhodopseudomonas* was begun by transferring one loop from the original ethyl alcohol enriched cultures into each of three sets of basal media enriched with 0.2 per cent, respectively, of sodium thiosulfate, sodium tartrate, and sodium citrate. The original sodium propionate enriched cultures were streaked onto peptone agar plates.

The species *R. palustris, R. spheroides,* and *R. gelatinosa* were isolated, respectively, from the subcultures in sodium thiosulfate, sodium tartrate, and sodium citrate media, and *R. capsulatus* was isolated from streaked peptone agar plates.

The biochemical characteristics given by Van Niel, and microscopic examination of the original lagoon samples and subsequent cultures which showed the presence of characteristic pigmented spheres and rods, were used to establish the ultimate identities of the four species of *Rhodopseudomonas.* No pigmented spirilla typical of *Rhodospirillum,* the other genus in this group, were observed.

Subsequent to the separation of the four species, large cultures for lagoon inoculation were grown in the basal medium containing ethyl alcohol in 1951 and 1953, and in the basal medium containing sodium acetate.

Preliminary Laboratory Study

Prior to introduction of the organisms into a test lagoon a controlled laboratory experiment was carried out with corn waste in an effort to establish the relationship of the bacteria to 5-day B.O.D. reduction, odor reduction, and pH. In this regard the results of a single test in which a series of mixed cultures of the non-sulfur purple bacteria were grown in decomposing corn waste indicated that the uninoculated controls showed a slightly greater over-all reduction in B.O.D. than did the units containing the bacteria. A similar set of cultures indicated no offensive odor in the units inoculated with the bacteria after the eighth day in the period of waste stabilization as compared to after the seventeenth day in uninoculated controls, and indicated the bacterial growth appeared in decomposing corn waste in the pH range from 7.7 to 7.9. In a subsequent series in which each of four species was cultured separately in a synthetic pea waste, the units inoculated with *Rhodopseudomonas spheroides* and *R. gelatinosa* showed improved odors in twelve days as compared to no similar degree of improvement in seventeen days in the two other inoculated units and the controls. Of the two units showing early improvement, the one inoculated with *R. spheroides* was judged least offensive and the odor was described as phenolic. The synthetic pea waste was prepared by mixing a 4½-oz. can of strained peas in 10 l. of distilled water. Odor types recorded in the laboratory and from the lagoons in 1951 and 1952 were classified as offensive, mild, or pleasant. They were based on the judgment of two or more

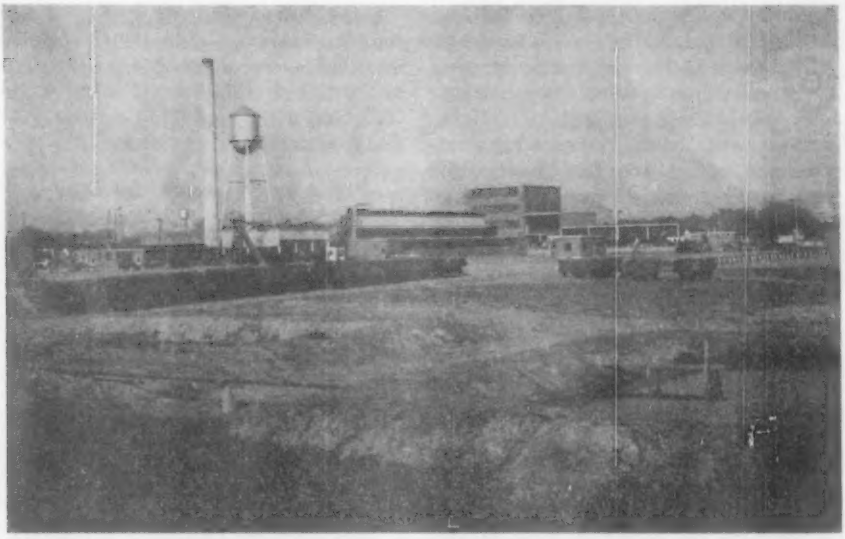

FIGURE 1.—Experimental lagoons No. 1 (left) and No. 2 (right) at Green Giant Company canning plant, Glencoe, Minn.

persons and were made on lagoon samples immediately after their arrival in the laboratory. It was necessary for practical reasons to adopt a limited method to show only large comparative differences.

Field Study

Field studies of the organisms were carried out in test lagoons furnished by the Green Giant Canning Company at Glencoe, Minn. The lagoons identified as No. 1 (north) and No. 2 (south) are shown in Figures 1 and 2. Lagoon No. 2 was used as a control. The square lagoons were 73 ft. on a side measured at the top of the berm and had a capacity of 115,000 gal. at an average depth of 3.5 ft., the greatest average depth attained. The total depth of each was approximately 4 ft. Seasonal studies were begun on the first day of lagoon operation (July 13, 1951; July 3, 1952; and July 11, 1953). Samples were collected in these years, respectively, in the periods from July 20 to October 30, July 10 to September 24, and July 21 to September 16.

During each season the study was in progress both lagoons were observed and sampled approximately once a week. Water temperatures, depths, color, and odor were recorded for each lagoon and samples were collected for the following determinations: C.O.D. (chemical oxygen demand), 5-day B.O.D., organic nitrogen, ammonia nitrogen, sulfate ion, total phosphorus, total alkalinity, plankton count, and pH. These data are summarized in Tables I, II, and III.

Lagoon Operation

Waste was supplied to the lagoons by an extension of a 4-in. tap from the main plant sewer, and flow into each lagoon was controlled by separate gate valves. In the 1951 season the lagoons were nearly filled during each pack. This necessitated pumping out part of the accumulated pea waste to provide room for corn waste. In subsequent seasons, schedules were established to provide for the uniform addition of waste throughout the canning season, filling each lagoon once.

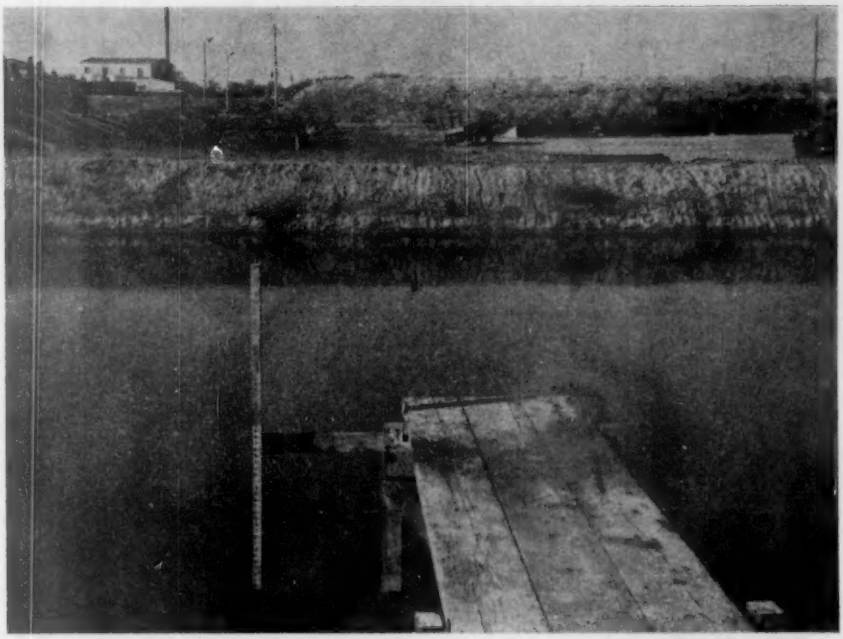

FIGURE 2.—Staff gauge and sampling dock in experimental lagoon No. 1.

Inoculation, Nutrient Addition, and Algal Control

In the plan for the field studies, consideration was given to three possibilities which were thought to be the most likely reasons for the late appearance of the pigmented bacteria. These possibilities were that: (a) the non-sulfur purple bacteria experienced an unusual lag in population growth which prevented early large-scale development; (b) the required, simple organic nutrient materials were not available until the waste had undergone partial decomposition; and (c) growth of the non-sulfur purple bacteria might be inhibited under lagoon conditions by competition and light screening from green algae and associated aerobic organisms.

In the 1951 season massive inoculation of the first flow of raw waste was carried out in an attempt to establish early growth of the bacteria and counteract any unusual lag in their population growth. The inoculation was made on July 13, when 5 gal. of a culture of *R. spheroides* were added to lagoon No. 1. Evidence of growth of the bacteria was first noted on August 13 in both lagoons Nos. 1 and 2. The inoculation of lagoon No. 2 was attributed to the action of birds and insects or the presence of the bacteria in the raw waste or the bottom soil of lagoon No. 2. This experience indicated that the size of inoculation had little effect in promoting growth of the bacteria.

Growth in the two lagoons, as indicated by their reddish color, lasted until sometime between visits on August 31 and September 6. Pigmented growth in citrate, tartrate, propionate, and thiosulfate enriched basal media which was inoculated with lagoon water collected at the time of visible evidence of growth, indicated that at this time several species of non-sulfur purple bacteria were present.

Although improved odors were re-

TABLE I.—Summary of Physical and Chemical Data from Test Lagoon No. 1 for the Periods of Addition and Periods of Stabilization of Pea and Corn Waste Separately and for the Entire Season

Determinations[1]	Type of Waste	Mean Value[2]								
		1951			1952			1953		
		Period of Add.	Period of Stab.	Entire Season	Period of Add.	Period of Stab.	Entire Season	Period of Add.	Period of Stab.	Entire Season
Temperature (° F.)	Pea	82	73	—	83	80	—	79	81	—
	Corn	71(8)	59	70(16)	77	70	79	76	—	77
pH	Pea	6.6	7.3	—	6.8	8.6	—	6.9	8.4	—
	Corn	6.5	7.8	6.9	6.4	8.3	7.4	7.1	—	7.4
Sulfates	Pea	19.1	11.0	—	20.9	9.7	—	—	3.3(1)	—
	Corn	28.0	4.4	18.1	4.8	4.8	10.5	21.6	—	18.5(6)
Organic nitrogen	Pea	20.0	11.0	—	34.4	17.3	—	22.0	20.5	—
	Corn	20.6(6)	14.5	18.0(14)	18.7	20.8	22.8	13.6	—	16.4
Ammonia nitrogen	Pea	15.1	42.0	—	2.9	4.1	—	34.0	15.5	—
	Corn	9.0(6)	8.8	12.6(14)	2.7	0.2	2.9	12.7	—	16.1
Total phosphorus	Pea	7.4	6.0	—	7.2	4.0	—	11.0	8.5	—
	Corn	6.1(5)	5.0(3)	6.1(12)	5.0(2)	5.5	5.5(9)	9.7	—	9.6
Total alkalinity	Pea	663	700	—	387	467	—	680	580	—
	Corn	521	622	582	470(2)	—	437(8)	650(4)	—	634(7)
Chem. oxy. demand	Pea	1,280	1,200	—	1,374	807	—	1,500	705	—
	Corn	1,336	1,137	1,262	810	690	952	1,376	—	1,224
B.O.D.	Pea	1,367	970	—	623	103	—	1,200	161	—
	Corn	913	768	969	447(3)	96	361(10)	728	—	645
Avg. depth (ft.)	Pea	1.8	2.1	—	1.5	1.6	—	1.4	1.8	—
	Corn	2.1	2.0	2.0	2.3	1.9	1.8	2.9	—	2.4
Odor[3]	Pea	M(1),O(2)	M(1)	—	M(1),O(1)	M(2)	—	—	—	—
	Corn	P(1),M(4),O(2)	M(4)	—	M(2),O(1)	M(1)	—	—	—	—
Number of samples	Pea	3	1	—	3	3	—	1	2	—
	Corn	7	4	15	4	1	11	5	0	8

[1] In parts per million except temperature, pH, depth, and odor.
[2] Value in () is number of samples if different than indicated at bottom of table.
[3] Numbers following letter designations indicate number of samples judged as mild (M), pleasant (P), and offensive (O).

TABLE II.—Summary of Physical and Chemical Data from Test Lagoon No. 2 for the Periods of Addition and Periods of Stabilization of Pea and Corn Waste Separately and for the Entire Season

Determinations[1]	Type of Waste	Mean Value[2]								
		1951			1952			1953		
		Period of Add.	Period of Stab.	Entire Season	Period of Add.	Period of Stab.	Entire Season	Period of Add.	Period of Stab.	Entire Season
Temperature (° F.)	Pea	82	72	—	87(2)	81	—	80	81	—
	Corn	71	61	71	77	76	80(9)	76	—	78
pH	Pea	6.4	7.2	—	8.2	9.6	—	7.0	8.7	—
	Corn	6.8	7.9	7.0	6.6	7.7	7.8	7.8	—	7.9
Sulfates	Pea	9.7	10.0	—	30.4	9.2	—	—	5.1(1)	—
	Corn	25.4	4.5	16.3	19.2	4.8	18.8	9.5	—	8.8(6)
Organic nitrogen	Pea	21.4	11.0	—	11.1	8.0	—	28.0	15.6	—
	Corn	19.7(7)	17.3	17.7(15)	17.8	16.0	13.7	15.2	—	16.9
Ammonia nitrogen	Pea	15.2	39.0	—	1.8	0.2	—	19.0	4.8	—
	Corn	9.2(7)	11.1	12.9(15)	2.0	4.9	1.7	3.8	—	5.9
Total phosphorus	Pea	6.6	5.5	—	4.1	3.4	—	9.8	6.6	—
	Corn	5.6(5)	5.8(3)	6.4(12)	5.9(2)	6.8	4.7(8)	7.3	—	7.5
Total alkalinity	Pea	637	690	—	423	395	—	580	510	—
	Corn	530	598	577	385(2)	—	404(7)	595(4)	—	569(7)
Chem. oxy. demand	Pea	1,112	1,000	—	375	370	—	1,400	595	—
	Corn	1,219	1,225	1,187	915(3)	770	598(9)	732	—	781
B.O.D.	Pea	1,023	840	—	80	32	—	660	65	—
	Corn	769	1,225	941	670	530	351	260	—	261
Avg. depth (ft.)	Pea	2.2	2.6	—	1.8	2.0(3)	—	1.6	2.1	—
	Corn	2.6(7)	2.7	2.5(15)	2.9	3.0	2.3(11)	2.7	—	2.4
Odor[3]	Pea	M(1),O(2)	M(1)	—	M(2)	M(2)	—	—	—	—
	Corn	P(2),M(3),O(3)	M(3)	—	M(1),O(2)	O(1)	—	—	—	—
Number of samples	Pea	3	1	—	3	2	—	1	2	—
	Corn	8	4	16	4	1	10	5	0	8

[1] In parts per million except temperature, pH, depth, and odor.
[2] Value in () is number of samples if different than indicated at the bottom of the table.
[3] Numbers following letter designations indicate the number of samples judged as mild (M), pleasant (P) and offensive (O).

TABLE III.—Summary of Numbers and Types of Plankton Organisms in Lagoons Nos. 1 and 2.

Season	Period	Number Samples Collected	Number of Organisms per Sample[1] (1000's/ml.)								
			Blue Green Algae		Green Algae		Flagellated Protozoa		Colorless Protozoa		All Types
			Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.	Mean
			(a) Lagoon Number 1								
1951	Pea waste	4	—	—	80(3)	100	200(3)	500	10(1)	10	200
	Corn waste	11	40(4)	100	3,000	5,600	70	400	0.7(2)	1	2,900
	Entire season	15	40(4)	—	2,400(14)	—	100(14)	—	4(3)	—	2,200
1952	Pea waste	5	0.1(4)	0.2	3,000	10,400	7	20	7	20	3,000
	Corn waste	5	100(1)	110	3,500	6,000	80	360	4(3)	10	3,600
	Entire season	10	20(5)	—	3,300	—	50	—	6(8)	—	3,300
1953	Pea waste	3	—	—	1,500	3,800	130	240	4(1)	4	1,600
	Corn waste	5	—	—	1,100(4)	2,700	120	450	—	—	1,000
	Entire season	8	—	—	1,300(7)	—	120	—	4(1)	—	1,300
			(b) Lagoon Number 2								
1951	Pea waste	4	—	—	50(3)	100	330(3)	1,000	50(2)	90	300
	Corn waste	12	10(2)	10	1,700	3,300	270(11)	2,000	0.2(4)	0.4	2,000
	Entire season	16	10(2)	—	1,500(15)	—	280(14)	—	20(6)	—	1,600
1952	Pea waste	5	0.6(3)	0.7	1,400	5,300	20(4)	50	6(3)	20	1,400
	Corn waste	5	30(3)	100	1,200	3,800	1,000	4,000	0.1(1)	0.1	2,300
	Entire season	10	20(6)	—	1,300	—	600(9)	—	4(4)	—	1,800
1953	Pea waste	3	—	—	3,300(2)	5,000	700	1,000	—	—	2,700
	Corn waste	5	0.2(3)	0.5	3,700	6,000	20	40	1(4)	5	3,700
	Entire season	8	0.2(3)	—	3,600(7)	—	200	—	1(4)	—	3,300

[1] Value in () is number of samples averaged if different than total number collected.

corded in lagoons Nos. 1 and 2 during the period of growth of the non-sulfur purple bacteria, an early growth was not achieved, and neither the physical, chemical, nor plankton data (Tables I, II and III) were interpreted to suggest that the improved odors were due to the growth of the pigmented bacteria. Lagooned pea waste collected at this time (August 13) from the main waste lagoon, where no growth was visible, proved to be a suitable substrate and produced a good growth of these bacteria in the laboratory. Growth in the laboratory was evident in 24 hr. under conditions of continuous illumination, temperature at 68° F., and pH above 6.5. It appeared that conditions in the lagoon from July 13 to August 13 differed principally in respect to illumination and the nature of the substrate (degree of decomposition and availability of simple organic nutrients).

In the 1952 season fortification of the raw waste was attempted to supply nutrient material which might not be available to the bacteria during early stages of waste decomposition. Sodium acetate was known to be a satisfactory organic supplement to the mineral requirements of the non-sulfur purple bacteria, and cultures of *R. spheroides, R. capsulatus,* and *R. gelatinosa* grew rapidly in the laboratory in synthetic pea waste fortified with 50 to 500 p.p.m. of sodium acetate. For field trials, 100 lb., or an initial concentration of approximately 400 p.p.m., was added to lagoon 1 on the first day of operation, July 3. At the same time, 5 gal. of a mixed culture containing *R. spheroides, R. gelatinosa,* and *R. capsulatus* were added to lagoon No. 1. A mixed culture was prepared because in the previous season several species were found to be present after inoculation with a single type. There was, however, no indication by color that growth of these bacteria occurred in either lagoon No. 1 or lagoon No. 2 during the 1952 period of study. This precluded any evaluation of the bacteria in regard to their effect on odor.

These bacteria, as was indicated, are able to live under aerobic conditions with or without light, as well as under anaerobic conditions where they require light. It was thought that oxygen produced by photosynthetic green algae might provide a favorable environment for numerous interfering aerobic organisms. Moreover, the pigmented bacteria, although they are capable of using near infra-red light exclusively, also use light at the red end of the visible spectrum which may have been largely screened out by green algae. This suggested that the relatively large concentrations of green algae during the period of pea waste in 1952 (Table III) may have contributed to conditions which prevented growth of the non-sulfur purple bacteria.

In the 1953 season an attempt was made to reduce the interference from algae and promote growth of the pigmented bacteria. Prior to the canning season in 1953, mixed cultures of the bacteria and green algae (principally *Chlorella sp.*) had been cultured in separate sets of synthetic pea waste containing 2, 4, 6, and 8 p.p.m. nigrosine dye. Nigrosine dye was used to screen out light* and reduce the growth of algae. Satisfactory growth of pigmented bacteria was obtained at each concentration. Algal growth, as indicated by numbers per milliliter, was reduced to at least one-third by each concentration compared to controls, and approximately to the same degree by 4 p.p.m. as by 8 p.p.m. It appeared from this that an initial concentration of 4 p.p.m. might be satisfactory in the lagoon.

At the time of the first addition of pea waste to the test lagoon, and on each subsequent visit except that of

* The light-screening properties of nigrosine are believed to affect the transmission of red light (used by pigmented bacteria) less than the shorter wave lengths (used by green algae).

August 20, nigrosine dye was added in an amount sufficient to give a concentration of 4 p.p.m. Sodium acetate was added in an initial concentration of approximately 200 p.p.m. and the lagoon was inoculated with a mixed culture of non-sulfur purple bacteria. Five gallons of culture containing *R. spheroides, R. gelatinosa* and *R. palustris* were added to lagoon No. 1 on July 11. There was no apparent growth of the pigmented bacteria at any time during the season. The effect of the dye in controlling algae was measured by comparing the average number of all types of plankton organisms per milliliter (Table III). The calculated reduction in algal population brought about in lagoon No. 1 during the period of pea waste was 41 per cent compared to the same period in lagoon No. 2, and 47 per cent compared to the period of pea waste in lagoon No. 1 in the previous year. Comparisons were made using the limited number of samples in the period of pea waste because of an accidental over-addition of waste on August 20 which filled lagoon No. 1 to overflowing, thus greatly diluting the inoculated and nigrosine-treated lagoon content. This abrupt change in the environment interfered with the direct interpretation of the action of nigrosine in regard to algae control after this date. The dilution also may have prevented the occurrence of a large growth of pigmented bacteria. The physical, chemical, and biological data (Tables I, II, and III), which were collected as in previous seasons, gave no explanation for the lack of growth of the non-sulfur purple bacteria in this season.

Discussion

The consistent ease with which growth of the organisms could be established in the laboratory contrasted sharply with results obtained in the lagoon. Foremost among the conditions which may have been responsible for this difference appear to be the intensity and periodicity of light. Both synthetic pea waste and actual lagooned waste served as suitable media for growth of pigmented bacteria in the laboratory where organisms were grown under continuous illumination. Another condition which may be partly responsible for failure of early growth in the lagoon might be related to the addition of waste. Dilution by periodic addition of fresh waste to the lagoons in the early weeks of the season may have kept concentrations of nutrient decomposition products below a level necessary to support visible growth. The added nutrient material may have been insufficient and may have been quickly consumed by other bacteria initially more abundant. In the laboratory, where growth was consistently obtained, dilution of the initial waste to replace evaporation loss, if required, was percentage-wise much lower than in the lagoon. Also, the probable presence of fewer competing organisms in the laboratory might lower the nutrient level required to support visible growth under laboratory conditions.

The pH levels at which bacterial growth developed in the laboratory ranged from 65° to 85° F. Tempera- with an initial substrate pH of near 7. In lagoon No. 1 this range was exceeded in 1951 by three values with a high of 8.4, in 1952 by three values with a high of 9.6, and in 1953 by two values with a high of 8.9. The high values occurred near the time of first addition of corn waste, and conditions of pH in lagoon No. 1 appeared favorable during the early part of each season when bacterial growth was desired.

The temperature levels at which growth developed in the laboratory ranged approximately from 5.0 to 8.0, tures in lagoon No. 1 during the three seasons ranged within or close to these limits, except in late September and October in 1951. Minor general differences appear in temperature variations from season to season, but it does not appear that temperature was a

limiting factor in the growth of the bacteria in the lagoon.

Differences between the experimental lagoon and the control in concentrations of recorded chemical constituents in the period of pea waste in the 1952 season may have resulted from dilution by a greater volume of holdover from the previous season and in the period of corn waste in the 1953 season.

The problem of adjusting the lagooned waste to make it suitable for an early growth of the non-sulfur purple bacteria may be centered in competition from other groups of bacteria. Other groups initially abundant and normally active in decomposition of these wastes may find the adjusted environment also particularly suited to their needs. Whatever the possibilities, the adjustments attempted by inoculation, addition of nutrient material, and control of algae did not promote an early growth of the non-sulfur purple bacteria.

Summary and Conclusions

1. Prolific growths of pigmented bacteria which appeared to be accompanied by periods of reduced odor offensiveness have been reported in canning waste lagoons in Minnesota. The present study was initiated to evaluate the feasibility of using these organisms as a biological means of controlling odors.

2. The pigmented organisms isolated from lagoon samples were identified as belonging to the genus *Rhodopseudomonas* of the group of non-sulfur purple bacteria (*Athiorhodaceae*). The four species isolated were: *R. spheroides, R. gelatinosa, R. palustris* and *R. capsulatus.*

3. Prior to field studies involving these organisms, laboratory experiments indicated that growths of the non-sulfur purple bacteria in corn waste resulted in earlier reduction of odor offensiveness.

4. An attempt to promote early growth of these bacteria in a test lagoon was made in 1951 by inoculation at the beginning of the season with a single species, *R. spheroides.* In 1952 the lagoon was inoculated at the beginning of the season with several species (*R. spheroides, R. gelatinosa* and *R. capsulatus*), and sodium acetate was added as a nutrient. In 1953 the lagoon was inoculated at the beginning of the season with several species (*R. spheroides, R. gelatinosa* and *R. palustris*), sodium acetate was added as a nutrient, and nigrosine dye was added to reduce competition from green algae and associated aerobic non-photosynthetic bacteria.

5. Growth of these bacteria was readily obtained in the laboratory in simulated pea waste and in samples of lagooned waste under continuous illumination at room temperature.

6. Growth of these bacteria in the test lagoon was obtained on one occasion late in the 1951 season, but establishment of an early growth in a lagoon was not achieved. Important factors related to growth under lagoon conditions appear to be illumination and availability of decomposition products.

7. Due to failure of the non-sulfur purple bacteria to grow in more than one season, and particularly to their failure to grow in the early part of any season, no evaluation could be made of their effectiveness in controlling or reducing odor under lagoon conditions.

Acknowledgments

The study described herein was carried out under the general direction of Harvey G. Rogers, Chief, Section of Water Pollution Control, Minnesota Department of Health, with the cooperation of the Green Giant Canning Company.

Reference

1. Van Niel, C. B., "The Culture, General Physiology, Morphology, and Classification of the Non-Sulfur Purple and Brown Bacteria." *Bact. Rev.* **8**, 1 (1944).

PILOT PLANT TREATMENT OF CITRUS WASTE WATER BY ACTIVATED SLUDGE *

By Robert R. McNary, Richard W. Wolford, and Marshall H. Dougherty

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Previous investigations (1) at the laboratory of the Florida Citrus Experiment Station indicated that the activated sludge process could be used to treat the waste water from the processing of citrus fruit. Since these studies were carried out on a very small scale and the raw waste was prepared by diluting canned orange juice with tap water, it was deemed highly desirable to repeat the work on a larger scale and to use actual wastes from a commercial citrus processing plant. The opportunity to do this presented itself when the authors were invited to assume operation of the activated sludge pilot plant of the Fosgate Citrus Concentrate Cooperative at Forest City, Fla.

In the small-scale studies in this laboratory (1), an excellent activated sludge culture had been built up while adding to the raw waste small amounts of sodium nitrate and trisodium phosphate. These added chemicals were gradually decreased and finally eliminated altogether from the raw waste without decreasing the effectiveness of the treatment. More recently an attempt was made to establish a new culture without the addition of these inorganic nutrients. After three weeks the culture was still slimy, the sludge did not settle well, the effluent was cloudy and the quality of the treatment was only fair. Once more the addition of sodium nitrate and trisodium phosphate to the raw waste brought about a marked improvement of the culture within three days. An additional six days were required for the culture to reach its best performance and appearance. In view of these findings it was decided to add these chemicals to the raw waste in the pilot plant.

* Cooperative research by the Florida Citrus Commission and Florida Citrus Experiment Station. Florida Agricultural Experiment Station Journal Series, No. 471.

Equipment

The pilot plant was located adjacent to the sand absorption beds which received all of the processing waste water from the Fosgate plant with the exception of the fruit washing, condenser, and other relatively uncontaminated water. Figure 1 shows a photograph and Figure 2 a schematic sketch of the pilot plant. The raw waste was picked up by the raw waste pump B from the citrus waste channel A and delivered to a cup suspended over a 500-gal. concrete surge tank H. During the latter part of the 43-day run, alkaline clean-up waste water, temporarily stored in drums C, was metered by pump D into the same cup. During the last three days of the run, dilution of the raw waste was accomplished by adding tap water through needle valve E to the same cup. Actually these three streams were run together through several feet of pipe before entering the cup to promote thorough mixing; this pipe is not shown in the sketch.

A small amount of the raw waste was continuously removed from the cup by the sampling pump Q and collected in a bottle R. The remainder of the raw waste overflowed from the cup into the surge tank H where it was mixed by the propeller-type agitator F and kept from becoming septic and odorous by

FIGURE 1.—Pilot plant for treatment of citrus waste water by the activated sludge process.

a stream of air from diffuser G. Each day 3 lb. 10 oz. of sodium nitrate and 1 lb. 1 oz. of trisodium phosphate were dissolved in 4.2 gal. of water and added to nutrient tank P. This solution was pumped at the rate of 11 ml. per min. to the overflow from the surge tank. The waste then flowed by gravity to the aeration tank J, which was also a 500-gal. concrete tank. Here the waste and sludge were thoroughly aerated with fine bubbles from four Saran-wrapped diffusers placed along the side of the tank. The air was supplied by blower I, which had a capacity of 60 c.f.m. at the shaft speed used. The exact amount of air actually used was not measured because of lack of a suitable metering device.

The mixed liquor overflowing from the aeration tank entered the 60-gal. clarifier L below the liquid surface. The sludge settling to the bottom was worked by a rotating scraper to the center, where it was picked up by the sludge recirculation pump M and returned to the upstream end of the aeration tank. The supernatant liquor overflowed into the effluent weirs S at the top of the clarifier and was piped to the sand absorption beds. When excess sludge was being withdrawn, a bypass valve in the sludge recirculation line was opened.

Procedure

From 7:00 AM to 3:00 PM, one of the authors was in attendance each day. During the remaining time an untrained operator was present. His sole duty, unless specifically instructed, was to collect samples and keep all electrical equipment operating. Daily composite samples of the surge tank overflow and effluent were formed of 100-ml. grab samples taken hourly. Also, 100 ml. were removed hourly from bottle R (Figure 2) and placed in a jug; this became the daily raw waste composite sample. These samples were stored in a water bath at 36° F. (2.2° C.) until sent to the laboratory.

The remaining waste in bottle R was

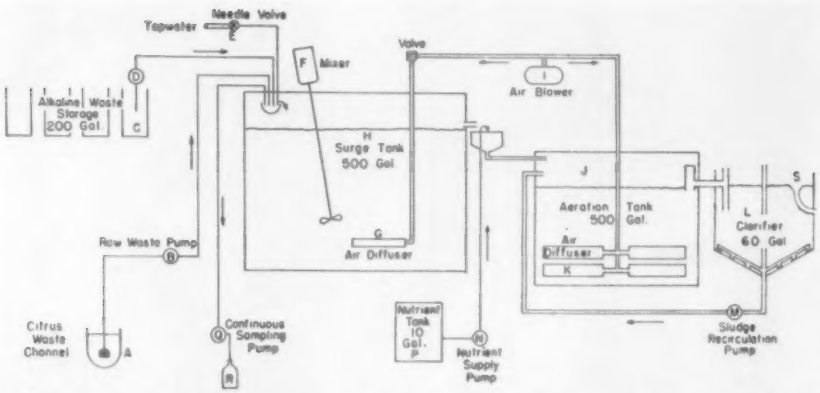

FIGURE 2.—Schematic diagram of pilot plant for treatment of citrus waste water by the activated sludge process.

returned to the surge tank. Several times during the day shift, the pH of the raw waste, surge tank overflow liquor, mixed liquor, and effluent were recorded. Also, the sludge percentage in the mixed liquor, sludge return liquor, and effluent were recorded. This determination was made by filling a 50-ml. graduated centrifuge tube with the liquor in question, centrifuging for 5 min. at 1,700 r.p.m. in a clinical-type centrifuge and reading the volume percentage of the sludge. This determination was non-standard, but was carried out this way because it was quick and gave the desired information concerning the quantity of sludge present. A drop of the mixed liquor was examined microscopically each day. The types and relative numbers of various protozoa were noted.

At the beginning of the run, it was intended to start with a supply of activated sludge from a sewage treatment plant. However, only primary sludge was available at that time and so 30 gal. were obtained and added to the aeration tank. Water was added to fill the tank and the blower was started. Feeding of raw waste and of the nutrient solution was not started until the next day. Within three days the color of the sludge changed from the gray of primary sludge to the tan of activated sludge. The protozoa population took about eight to ten days to become stabilized. The sludge started to settle well in three days, but the supernatant liquid did not clear up until the protozoa population became stabilized.

Analysis of the waste samples for total and volatile solids and for 5-day B.O.D. was carried out in the laboratories of the Minute Maid Corporation, located about 15 miles away. While this was a great assistance to the authors, nevertheless it was not possible to calculate the load on the plant soon enough so that the plant operation could be based on these analytical results, but had to be based on the sludge color, pH, temperature, rate of settling, and the amount of froth present. Thus it became apparent that a quick and reasonably accurate determination of the strength of the raw citrus waste would have been very helpful in the operation of this plant. The usual Brix determinations used in citrus plants were not adequate for this purpose.

Experimental

The test data are presented graphically in Figures 3 through 8. Although there are a few blank spaces in the data caused by unavoidable mishaps, it is believed that the analyses give a fairly

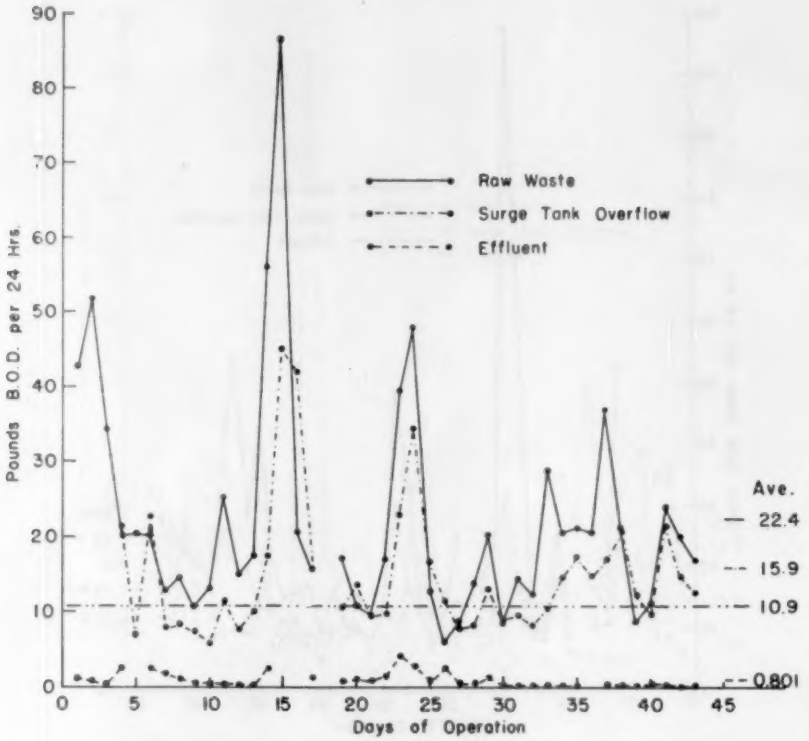

FIGURE 3.—B.O.D. in raw citrus waste, surge tank overflow, and effluent during pilot plant operation.

accurate picture of the conditions as they existed. The performance of the pilot plant in reducing the B.O.D. of the raw waste is given in Figure 3. The average values of the B.O.D. (in pounds per 24 hr.) of the raw waste, surge tank overflow, and effluent for the entire run are given at the right. The broken horizontal line indicates the calculated capacity of the plant (exclusive of the surge tank) based on previous laboratory results (1). On this basis the pilot plant was, on the average, overloaded 46 per cent.

The performance of the pilot plant in reducing total solids and volatile solids is shown in Figure 4 and Figure 5, respectively. Here also, the averages are given at the right. The 5-day B.O.D. in parts per million of daily composite samples of the raw citrus waste and the volatile solids in percentage are shown in Figure 6. On the basis of a few scattered analyses in the past, a raw waste having about 2,000 p.p.m. B.O.D. had been expected and the daily volume of waste to be treated was predetermined in the beginning from this value. The average B.O.D. for the first five days turned out to be 8,602 p.p.m.

The system was therefore overloaded at the start. By the time it had recovered from this situation, a power failure in the citrus plant from an electrical storm caused the dumping of 1,200 gal. of partially concentrated orange juice into the waste line during the night of the 14th day. The extent and seriousness of this excessively

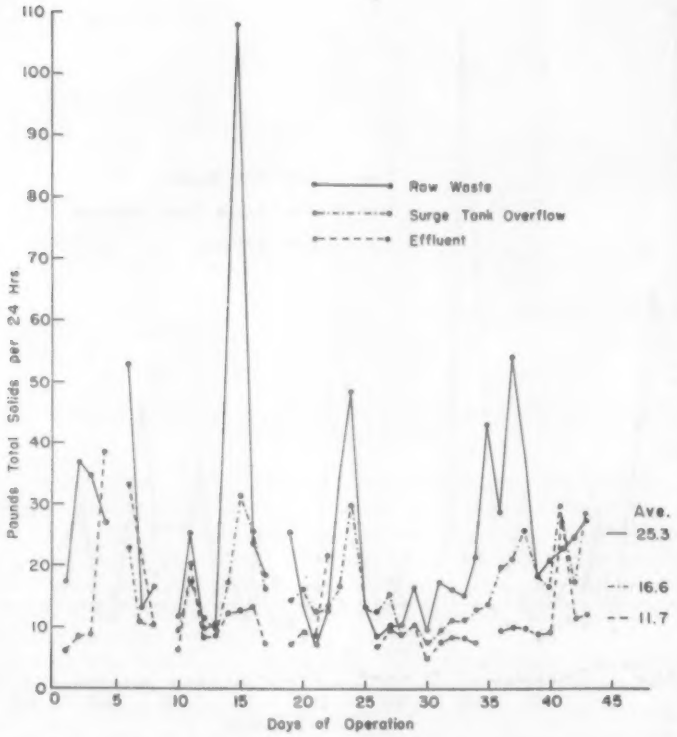

FIGURE 4.—Total solids in raw citrus waste, surge tank overflow, and effluent.

strong raw waste overload was not realized immediately. By the 18th day, frothing became so bad that feeding raw waste was stopped almost entirely for the day.

During this overloaded period, on the 17th day, it was noticed that the mixed liquor in the aeration tank felt quite warm while a sample was being withdrawn. The temperature of this liquor was 106° F. (41° C.). Thereafter this temperature was observed and recorded each hour. There was, of course, a regular daily rise in the temperature during daylight and a lowering at night. The temperature of the surge tank liquor followed the same diurnal cycle. Since the rate of metabolic activity in this tank was comparatively low, this temperature served as a continuous reference point for judging the significance of the mixed liquor temperature.

It was found that the difference between the two temperatures served as a useful indicator of the activity of the activated sludge, under the conditions of this run. A difference of 2° or less indicated an activity less than normal; 4° or 5° difference appeared to be optimum; over 6° indicated overload conditions. If these conditions were allowed to persist too long it would lead to frothing, bulking sludge, and other troubles. The first time the temperature of the mixed liquor was measured (106° F.), the difference between the temperatures was 20° F.; this was truly a heavy overload indication, as indeed was the case.

The microorganisms, particularly the protozoa, in the sludge were seriously

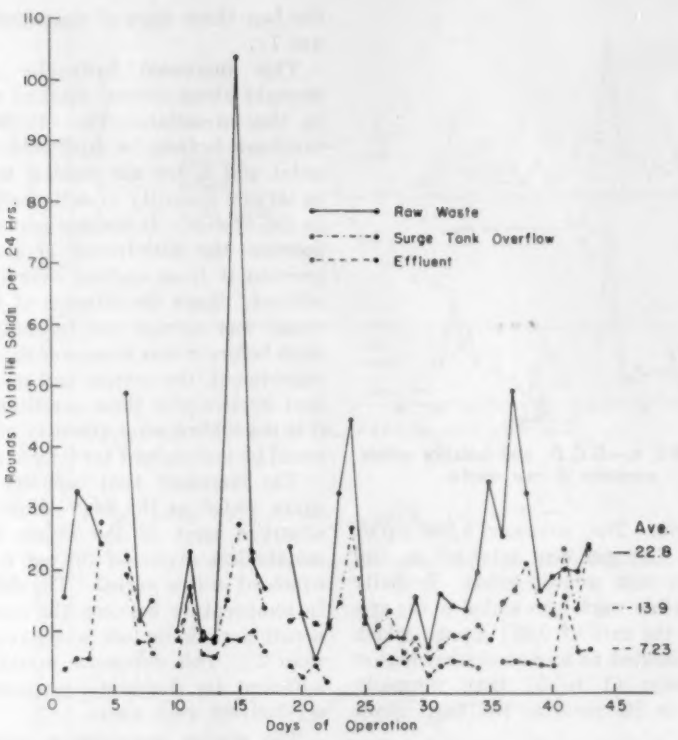

FIGURE 5.—Volatile solids in raw citrus waste, surge tank overflow, and effluent.

injured by the high overload temperatures. It is believed that this is the first recorded instance in which an activated sludge unit has been so overloaded that the heat of its own activity raised its temperature so high that serious harm was done to the microorganism population. After exposure to this high temperature, the protozoa practically disappeared from the culture. Their reappearance during the ensuing week was gradual and full recovery with the return of plentiful *Vorticella* required about 10 days. It was observed that the rate of settling of the sludge recovered more quickly than did the reappearance of the protozoa; the effluent, however, was cloudy until the protozoa regained their normal population. The presence of numerous active *Vorticella* upon microscopic observation has been found to be an indication that the activated sludge is in good condition. The maximum daily temperatures of the surge and aeration tank liquors are given in Figure 7.

It was mentioned under "Equipment" that special provision was made to collect separately the strongly alkaline waste water that was produced during clean-up periods in the citrus plant. This material has caused difficulty before in the treatment of citrus wastes (2). On the other hand, it was found in the laboratory studies that, in the absence of added nitrates and phosphates, the inclusion of an alkaline substance helps maintain a favorable pH in the mixed liquor.

Two batches of the alkaline waste were collected and added continuously to the raw waste during the last 9 days

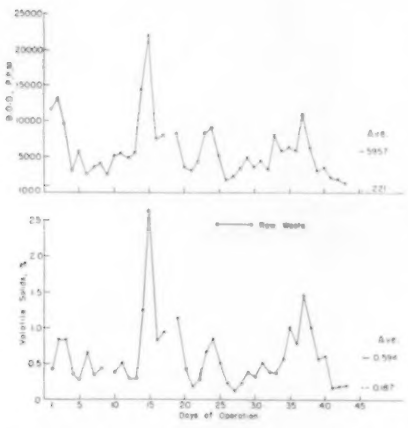

FIGURE 6.—B.O.D. and volatile solids contents of raw waste.

of the run. They averaged 6,560 p.p.m. B.O.D., 1.89 per cent total solids, and 0.92 per cent volatile solids. Initially the alkaline waste was added to the system at the rate of 0.051 g.p.m., which was estimated to be a somewhat higher proportion (1 to 5) than normally would be its ratio to the total plant wastes.

After six days of operation at this ratio, the proportion of alkaline waste was reduced to one-half the value. The effect of adding the alkaline waste on the pH of the raw waste is shown by the solid line in Figure 7. The alkali was neutralized in the surge tank liquor by acid production at this point, since this liquor always remained slightly acid. There was no significant change in the pH of the mixed liquor when the alkaline waste was added, probably because the mixed liquor was already adequately buffered.

Not all citrus plants discharge a waste water as concentrated as was encountered in this study. To gain some experience in treating a weaker waste with this pilot plant, tap water was added, along with the reduced quantity of alkaline waste, to the normal raw waste so that the combined rate amounted to just about 1 g.p.m. during the last three days of operation (Figure 7).

This increased hydraulic loading brought about several marked changes in the operation. The clarifier was overloaded from a hydraulic standpoint and it was not possible to retain as large a quantity of activated sludge in the system. It became necessary to increase the withdrawal of sludge to prevent it from spilling over into the effluent. Since the dilution of the raw waste was carried out for only three days before it was necessary to stop the experiment, the system had not stabilized itself under these conditions, and it is not known what quantity of sludge could be maintained for longer periods.

The increased heat capacity of the extra water in the more dilute waste absorbed most of the excess heat of metabolism given off during a strong overload in this period. The difference in temperature between the surge and aeration tank liquors was never more than 2°. This difference would not be sufficient for diagnostic purposes with a relatively weak waste.

The sludge percentages have been plotted in Figure 8; the upper line indicates the amount of sludge in the sludge return liquor; the middle line, the sludge in the mixed liquor of the aeration tank; and the bottom line, the sludge in the effluent. Appreciable amounts of sludge at times occurred in the effluent as the result of overloaded conditions. During the last three days of operation when tap water was being included in the raw waste, the amount of sludge in the effluent, both before and after frequent withdrawals of sludge, was determined. The double plotting of the sludge percentages was made to show that whereas sludge was lost at that time, a clear effluent could be obtained when there was sufficient space and time for the sludge to settle out. The upper values were obtained before, and the lower values obtained after sludge withdrawal. In that period, also as previously mentioned, the

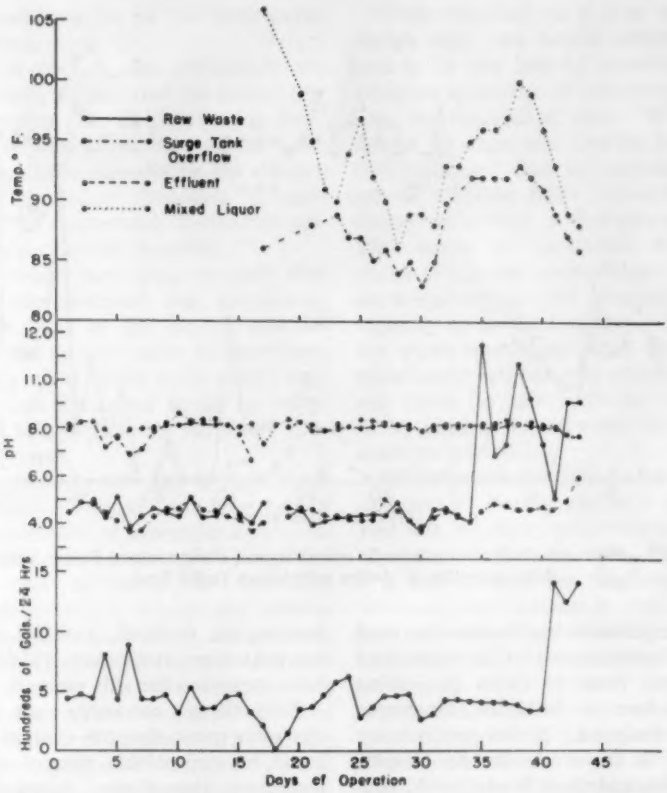

FIGURE 7.—Maximum daily temperatures of surge tank liquor and mixed liquor; variation in pH of raw waste, surge tank overflow, mixed liquor, and effluent; and volume of waste put through pilot plant in 24 hr.

clarifier was hydraulically overloaded and sludge spilled over into the effluent even though its settling properties were excellent. The solid line in Figure 8 shows the volume of sludge withdrawn during each day.

Discussion

Perhaps the most striking observation discernible from the data is the extreme variation in the strength of the raw waste. The strongest waste occurred on the 15th day, when a power failure made it necessary to empty 1,200 gal. of high-Brix juice into the waste line. Discounting the data for this day, the raw waste still showed such a large variation in strength from day to day that the treatment of the waste was made rather difficult.

It is believed that drippage from the waste peel bins was responsible for a major portion of the strength fluctuation. This drippage was very strong, and judging from past experience probably contained from 6 to 14 per cent total solids and a B.O.D. of 40,000 to 100,000 p.p.m. The volume of this strong waste depends upon the length of time the peel stays in the bins and a number of other factors. The utilization of this material in some other manner would simplify the treatment of the remaining waste waters.

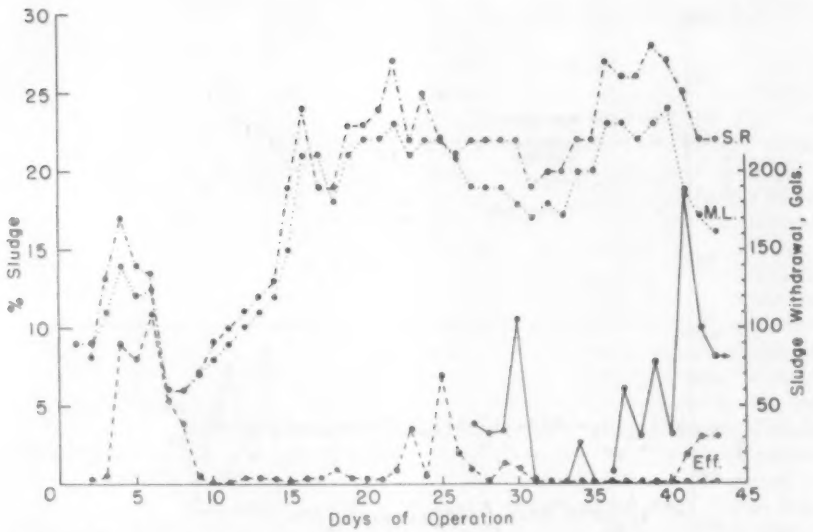

FIGURE 8.—Per cent sludge by volume in mixed liquor, sludge return liquor, and effluent. Also, quantity of sludge withdrawn (solid line).

This experience emphasizes the need of an adequate survey of the waste load discharged from a citrus processing plant before a full-scale treatment plant is designed. A few preliminary analyses of the waste at the Fosgate plant indicated their waste would contain approximately 2,000 p.p.m. B.O.D., whereas during the run the raw waste averaged 5,957 p.p.m. B.O.D. or about three times the expectation.

The surge tank in this installation served essentially as a holding tank to level out some of the short-term fluctuations in the raw waste. If it could have been operated as a true surge tank, wherein the contents were pumped to the aeration tank at a rate adjusted to the concentration of the waste and the condition and activity of the sludge, perhaps the shock loads on the system could have been eliminated and a much smoother operation obtained.

To do this properly, a quick and reasonably accurate determination of the waste concentration would be required. The oxygen consumed from permanganate test (3) and the chemical oxygen demand (C.O.D.) test using potassium dichromate (4)(5) have been suggested for this purpose.

Even though the surge tank did not eliminate gross strength changes in the waste, an appreciable amount of treatment took place there. Averaging the results of the entire run, the B.O.D. was reduced 29 per cent, the total solids 34 per cent, and the volatile solids 39 per cent by the activity in the surge tank.

Except at the time of serious overload and during the recovery thereof, the activated sludge system demonstrated notable ability to treat citrus wastes. There were 14 days out of the 43 in which the B.O.D. of the effluent was less than 50 p.p.m. and three days when the B.O.D. was less than 10 p.p.m. When the B.O.D. was low, the effluent was sparkling clear and odorless. Because of the nitrogen and phosphorous compounds added it should be useful as irrigation water. During the last 14 days of operation the over-all reduction of B.O.D. was slightly more than 99 per cent, whether calculated from

the pounds per 24 hr. or from parts per million.

In this respect, the pilot-plant results certainly confirmed the laboratory investigation (1). Reductions in total and in volatile solids were not so complete, for there remained in the effluent (under the most favorable circumstances) an appreciable amount of stable, non-putrescible material.

The results also demonstrated that an extreme overload was pernicious, but not fatal to the sludge culture. Slime-forming organisms, *Sphaerotilus*, became prolific under unfavorable conditions but decreased again to unimportant numbers under favorable conditions.

The recovery of the sludge from slimy conditions may have been helped by the addition of inorganic nutrients. The run was too short to determine either the minimum or optimum amounts of sodium nitrate and sodium phosphate to be added to citrus waste for efficient operation of the activated sludge process. The laboratory studies have indicated that only pH buffering was required, at least after the culture was once established. A favorable pH can be maintained by the addition of an alkali to the waste.

The data indicate that the alkaline waste from the citrus plant clean-up was treated satisfactorily when it was collected separately and mixed with the regular waste continuously. Figure 7b shows that the pH of the raw waste mixture was raised appreciably above neutrality by this addition of alkaline waste. There was sufficient production of organic acids in the surge tank to neutralize the alkali so that the pH of the liquor in this tank never became alkaline. Probably the inclusion of the alkaline wastes would serve to control the pH of the mixed liquor in the manner previously discussed. It was noted also that the strongly alkaline waste did not putrify noticeably during the several days that it was stored separately.

When starting up a new activated sludge unit, one would naturally expect to do this best by introducing an adequate quantity of activated sludge from an established unit. When this cannot be done, the present investigation indicated that an active culture can be obtained from primary sewage sludge with only a few days' delay. This might be important when the citrus processing plant begins the season's operations with practically full capacity from the first day. Bringing the waste treatment plant into correspondingly full capacity quickly would cut down or eliminate the necessity of by-passing waste water during the start-up period.

Variations in the rate of aeration were not studied during this run, since the run was too short to permit the investigation of many variables. The blower was not selected for this installation, but was used because it was available and had a capacity larger than the unit required. It had a capacity of 60 c.f.m. at 5 p.s.i. The pressure on the discharge line of the blower was measured several times at 4.5 p.s.i.; consequently, the blower should have delivered at least 60 c.f.m. There were not suitable measuring instruments available to confirm this estimate. It was noticed that the amount of air supplied to the aeration tank gradually decreased because of clogging of the air diffusers. The diffusers were cleaned twice during the run; probably this cleaning operation would become a frequent maintenance operation in a full-scale plant.

During periods of good operation of the pilot plant, the color of the liquor in the surge tank was light yellow and very little froth was present. The mixed liquor in the aeration tank was tan in color and the froth, if any, was thin and covered less than one-quarter of the surface. In the settling chamber or clarifier, the sludge settled rapidly and was covered with a clear supernatant liquid that usually had a slight tinge of yellow color but was clear and

practically odorless. When the alkaline waste was included, the color of the effluent was darker but still clear.

When an overload occurred, the first noticeable change was an increase in the temperature difference between the surge and aeration tanks. A difference of 6° or more indicated an overload for this pilot plant, but would not necessarily do so in another installation under unlike conditions. With overloading, froth on the aeration tank increased in volume and persistency, eventually overflowing the tank. Severe overloading caused frothing in the surge tank, but it was never as voluminous as in the aeration tank. In the meantime, in the clarifier, "lumps" of sludge started to float and pass out in the effluent. More and more sludge began to float and eventually it stopped settling and the effluent contained the same amount of sludge as did the mixed liquor.

Removal of the overload condition brought about recovery of the system in reverse order. The pH of the mixed liquor decreased during severe overload but was not considered as a reliable indicator of the condition of the activated sludge. Microscopic examination of a drop of the sludge can give an experienced operator a good indication of the condition of the sludge. A large population of protozoa, including many *Vorticella*, indicated an active sludge in good condition. *Vorticella* seemed to be the last type of microorganism to return in significant numbers after recovery from a severe overload.

This pilot plant was operated according to the premise that the more activated sludge present in the system the greater its capacity to treat the waste. Sludge was therefore not withdrawn intentionally until circumstances made it necessary. Several times during the run sludge was unavoidably lost from the system by passing out in the effluent when its settling characteristics deteriorated.

On the 24th day, however, it was necessary to withdraw sludge intentionally because its volume had built up to the point where no more could be held in the system, even though it would settle very well. To maintain a clear effluent, the excess sludge was withdrawn in varying amounts until the end of the run; this is a normal procedure with activated sludge plants. During the last three days, when the raw waste was diluted with water, much more sludge had to be withdrawn because the clarifier was not big enough to provide sufficient settling time with the increased volume of flow. There was not sufficient time to determine the percentage of sludge in the mixed liquor that could be retained in the system under these conditions. It is probable that in each installation the strength of the raw waste will determine the optimum amount of sludge that can be maintained, assuming that an adequate settling chamber is provided.

Disposition of the excess sludge was not investigated; except that on one occasion an attempt was made to filter it on a cloth-covered test filter without the use of any conditioning agents. The filtration was not too successful because the sludge still retained some sliminess that prevented building up a thick filter cake. Conditioning of the sludge with ferric chloride in a manner similar to the procedure used in sewage treatment plants might have provided a sludge that filters readily. In laboratory investigations, fast-filtering sludges have been obtained under ideal conditions without conditioning. It is probable that suitably filtered and dried sludge can be marketed for animal feed or fertilizer purposes (1).

Acknowledgments

The authors wish to express their appreciation for the opportunity to use the facilities of the Fosgate Citrus Concentrate Cooperative, Forest City, Fla., and to James M. Fiske and W. C.

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5. "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes." 10th Ed., Amer. Pub. Health Assn., New York, N. Y. (1955).

MEETINGS OF INTEREST

1956

Aug. 20–31 **Massachusetts Institute of Technology.** Disposal of Industrial Wastes by Biochemical Processing. Summer Session. M. I. T., Cambridge 39, Mass.

Aug. 22–24 **Hydraulics Division, American Society of Civil Engineers,** University of Wisconsin, Madison, Wis. Professor Arno T. Lenz, College of Engineering, University of Wisconsin, Madison 6, Wis.

Oct. 8–12 **Bavarian Biological Institute,** Munich, Germany. Advance Course on biology of sewage and stream sanitation. Dr. H. Liebmann, Bayerische Biologische Versuchsanstalt, Veterinarstrasse 13, Munich 22, Germany. Applications by Sept. 22.

Oct. 8–11 **Federation of Sewage and Industrial Wastes Associations,** Los Angeles, Calif.

Oct. 15–19 **American Society of Civil Engineers,** Annual Meeting, Pittsburgh, Pa.

Nov. 12–16 **American Public Health Association,** 84th Annual Meeting, Atlantic City, N. J.

Nov. 19–20 **Sanitary Engineering Division Conference,** American Society of Civil Engineers, Kansas City, Mo. A. D. Caster, Division Secretary, 38 Arcadia Place, Cincinnati 8, Ohio.

Stream Pollution

AQUATIC MACRO-INVERTEBRATE COMMUNITIES AS INDICATORS OF ORGANIC POLLUTION IN LYTLE CREEK

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Year-round field studies of the composition and ecology of stream communities associated with the purification of organic wastes in streams were initiated on Lytle Creek in October, 1949. This creek, which is located about 45 miles northeast of Cincinnati, Ohio, is a tributary of the Little Miami River. Its drainage basin comprises 27 sq. mi., a third of which is contained within the city limits of Wilmington, Ohio, a city of some 7,412 persons.

Lytle Creek is a permanent stream, approximately 11 miles long and has an average gradient of 25 ft. per mile. It is 3 to 35 ft. wide during low water stages and varies in depth from a few inches in the riffles to more than 6 ft. in a few pools. The principal natural source of water in the stream is surface drainage. This flow is augmented, however, at a point about 7.3 miles above the mouth, by the effluent from the Wilmington sewage treatment plant. Primary treatment including chemical precipitation was provided at this plant until 1954, when secondary treatment of the activated sludge type was installed. This improvement changed the stream conditions at that time. The plant treats an average of about 750,000 g.p.d. of sewage. The sewer system is of the combined type, and is overloaded during heavy rains. This necessitates bypassing a large part of the total flow directly into the creek. During low flow stage in summer and autumn, the sewage effluent comprises from 80 to 90 per cent of the total stream flow.

In the Lytle Creek investigations year-round studies have been conducted to determine seasonal variations in aquatic populations and environmental conditions. The environmental changes which occurred in the stream from October 1949 to June 1952 have been described by Gaufin and Tarzwell (1) (2), and the effects of sewage pollution on the fishes of the stream were considered by Katz and Gaufin (3). In this paper the composition and distribution of the invertebrate populations found in the various life (pollutional) zones of the stream at different seasons are considered in relation to the significant physical and chemical changes which have occurred. Further, an evaluation is made of the potential worth of these various invertebrate communities as indicators of the environmental conditions under which they exist.

Procedures

At the initiation of the Lytle Creek studies ten stations were selected for periodic sampling. These stations were designated by numbers which indicate their distance in miles from the stream mouth; namely, Stations, 0, 1, 2.8, 4.2, 5.2, 6.5, 7.2, 7.3 (sewage outfall), 7.6, and 8.7 (Figure 1). Monthly, or more frequently, samples were taken at these stations for the determination of dis-

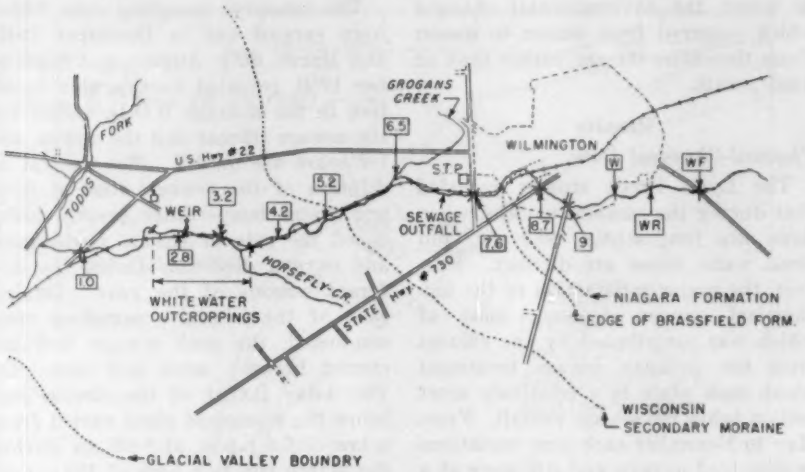

FIGURE 1.—Lytle Creek drainage basin.

solved oxygen, pH, CO_2, methyl orange and phenolphthalein alkalinity, and temperature. From July 1950 until the end of the study continuous measurements of stream flow were made by means of a sharp-crested, rectangular, contracted weir and a float-level recorder which were placed in the stream about 3 miles above its mouth.

Daily and seasonal physical-chemical variations were determined by taking during each season hourly samples at each of the stations over 24-hr. periods. During the first year of the study, five intensive 24-hr. sampling runs were carried out through the concerted efforts of biologists, bacteriologists, and chemists of the Center staff. In these studies samples of the sewage effluent were taken at each hour throughout a 24-hr. period. This selected 24-hr. discharge was followed downstream and sampled successively at each station over a 24-hr. period. Rate of flow was determined by the use of fluorescein dye placed in the stream just prior to the study. Dissolved oxygen and temperature determinations were made at each station every 2 hr. and samples were collected for bacteriological and chemical studies. Determinations of B.O.D.; oxygen consumed; pH; total alkalinity; chlorides; total and soluble phosphates; and ammonia, organic, nitrite, and nitrate nitrogen were made on 24-hr. composited samples from each of the stations. Determinations of coliform organisms and enterococcus densities were also made.

During the second year of the study nine additional 24-hr. sampling runs were conducted. Hourly studies were made at each station during 24-hr. periods for the determination of air and water temperatures, dissolved oxygen content, and pH.

From January 1950 through December 1951, quantitative bottom samples were taken at monthly intervals from pools, runs, and riffles at each station. A Surber square-foot sampler was used in the riffles and runs, whereas a Peterson or Ekman dredge was used in the pools. Marginal samples were taken by means of a special sampler formerly used by the junior author (4).

During 1952 the quantitative samples were supplemented by large qualitative collections taken from all sections of the stream by means of a Needham handscreen sampler or a Ward's sieve net. These collections were made

to detect the environmental changes which occurred from season to season along the entire stream, rather than at fixed points.

Results

Physical-Chemical Data

The Lytle Creek studies revealed that during the summer months, when flows are low, septic, recovery, and clean water zones are distinct. Further, the major satisfaction of the biochemical oxygen demand, most of which was contributed by the effluent from the primary sewage treatment plant, took place in a relatively short section below the sewage outfall. From May to November each year variations in dissolved oxygen and pH were at a maximum, and the most severe conditions of oxygen depletion occurred. During the winter months higher flows and lower temperatures resulted in the pollutional zones changing their location and extent. During the period from December to April, natural purification proceeded at a slower rate, sewage fungus grew farther downstream, and dissolved oxygen was abundant throughout the stream.

Maximum and minimum flow rates and temperatures are given in Table I. In general, the summer and autumn months were periods of low flow and high temperatures, whereas during the winter and spring months the reverse condition prevailed.

The intensive sampling runs which were carried out in December 1949, and March, July, August, and September 1950, revealed considerable variation in the average B.O.D. values for the sewage effluent and the stream water below the outfall. The amount of dilution of the sewage, time of flow, and water temperature greatly influenced the rate of stream purification and oxygen depletion during the different seasons of the year. During each of the intensive sampling runs conducted, the peak sewage flow occurred between noon and midnight. The 5-day B.O.D. of the stream just below the treatment plant varied from a low of 6.8 p.p.m. at 8:00 AM during the March run to a high of 193 p.p.m. at 6:00 PM during the August run. The former low B.O.D. resulted from the dilution of the small night-time sewage flow by the greater stream flow occurring at the time of the study.

The satisfaction of the 5-day B.O.D. as the water moved downstream during four of the 24-hr. studies is shown in Figure 2. The average 5-day B.O.D. at the different stations is shown in Figure 3. Eighty per cent of the B.O.D. was satisfied in the first three miles of stream below the sewage outfall in all except the March run. On that occasion low water temperature (average 40° F.), which decreased bacterial activity, and the much greater runoff, which reduced the time of flow,

TABLE I.—Extreme Physical and Chemical Variations, Lytle Creek 1949–52

Item	Maximum			Minimum		
	Sta.	Value	Sample	Sta.	Value	Sample
Flow (c.f.s.)	2.8	100+	Mar. 1951	2.8	1.0	Aug. 1951
Time of flow (days)	—[1]	7 to 8	Aug. 1950	—[1]	1½	Mar. 1950
Water temp. (°F.)	2.8	91	July 1952	2.8	32	Jan. 1951
B.O.D., 5-day (p.p.m.)	7.2	193.0	Aug. 1950	7.2	6.8	Mar. 1950
Diss. oxygen (p.p.m.)	5.2	19.4	May 1951	5.2	0.0	Aug. 1951
pH	2.8	9.1	May 1951	7.2	6.9	Aug. 1951
Tot. alk., as $CaCO_3$ (p.p.m.)	4.2	318	Dec. 1949	1.0	169	Dec. 1949
Tot. phosphate, as PO_4 (p.p.m.)	6.5	26.2	Dec. 1949	7.6	0.55	Aug. 1950
TKN-N (p.p.m.)	6.5	38.0	Dec. 1949	7.6	0.04	Mar. 1950

[1] Sewage plant to mouth.

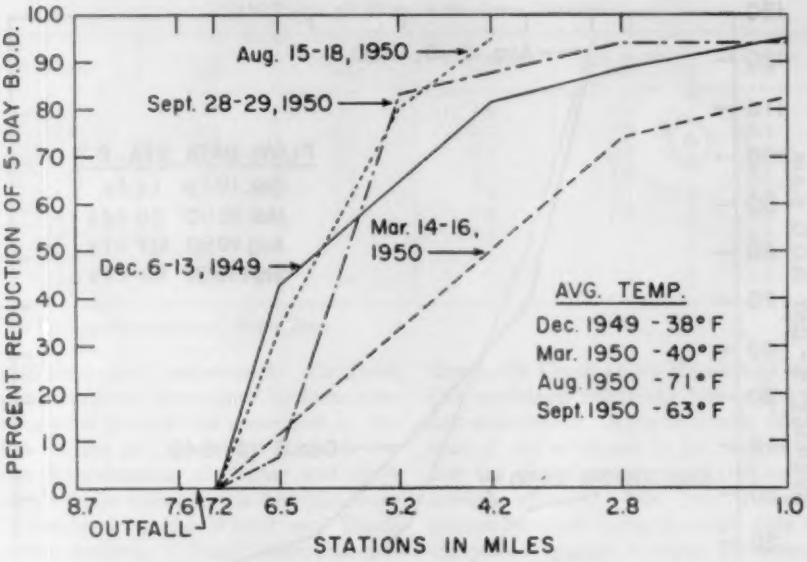

FIGURE 2.—Rate of satisfaction of B.O.D. in Lytle Creek, 1949–50.

resulted in the water flowing 5.5 miles before a similar B.O.D. reduction was obtained. During the March run a stream section moved four miles in 20 hr. whereas during July, September, and December, 36 to 48 hr. were required for travel of only two miles. Time of flow was, therefore, about four times as long in the latter studies as it was in March.

The nutrient content of the water just below the sewer outfall varied considerably depending upon the time of day, the season, the amount of dilution, the temperature, and other factors. In general, however, the analyses of water samples revealed that nitrogen in its various forms and the total phosphates, which were present in only small quantities in the stream above the sewage outfall, were contributed in large amounts by the sewage, and underwent a gradual but marked reduction as the water moved downstream. For example, from August 15 to 18, 1950, during a period of low flow, 24-hr. composite water samples taken at a point 0.2 miles above the outfall contained 1.40 p.p.m. total phosphates expressed as PO_4 ions, and 1.11 p.p.m. total Kjeldahl nitrogen; those taken 0.1 mile below the outfall contained 12.0 and 28.7 p.p.m., respectively. Water samples taken from the stream at a point about three miles below the outfall contained 8.0 p.p.m. total phosphates and 18.6 p.p.m. total nitrogen. A heavy rain prevented the completion of this study, but water samples taken from near the mouth of the stream during similar periods of low flow yielded phosphate and nitrogen values similar to those found in the stream above the sewage treatment plant, indicating a return to normal stream conditions.

Determinations of pH and alkalinity of water samples taken during the various 24-hr. sampling runs revealed that these environmental factors were at all times favorable to the production of a varied fauna in any section of the stream. The maximum and minimum pH and total alkalinity values recorded from the stream during the study are listed in Table I. The pH of the sewage effluent was neutral or slightly acid

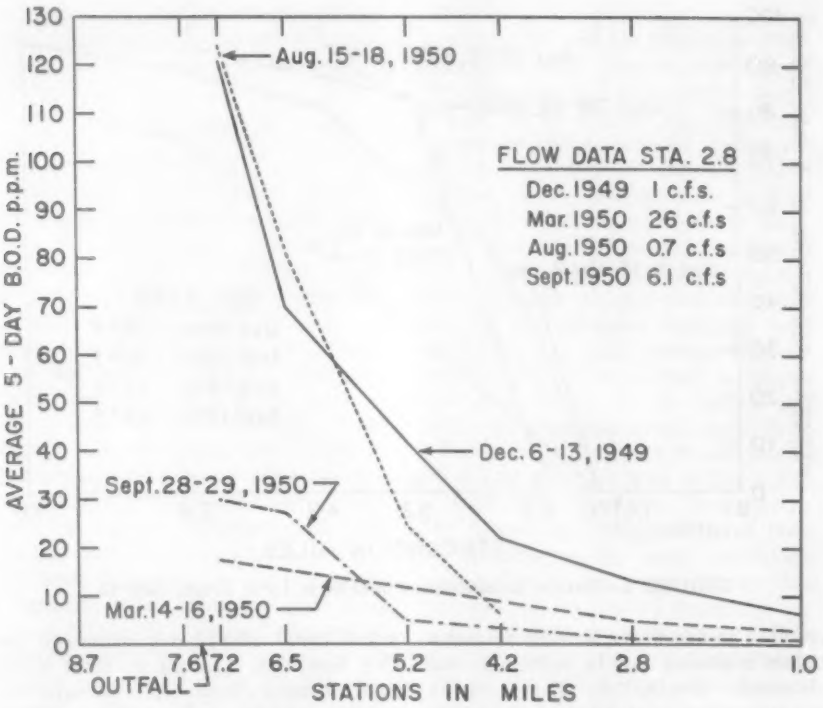

FIGURE 3.—Range in B.O.D., Lytle Creek, 1949–50.

during dry periods, but ranged from 7.0 to 8.5 during periods of heavy precipitation. The pH values increased progressively downstream from the sewage outfall. (Table II). Methyl orange alkalinity values, recorded as p.p.m. $CaCO_3$ equivalent, were in excess of 168 p.p.m. at all times.

Lakes and streams normally exhibit a noticeable diurnal variation in their dissolved oxygen content (5)(6)(7)(8)(9)(10)(11)(12). In streams polluted with domestic sewage this variation is usually more marked in certain sections due to dense algal growths and the large oxygen demand of the organic material. In Lytle Creek diurnal variations due to these factors were most marked in the recovery zone.

During the summer months, the dissolved oxygen content in the four-mile section below the sewage treatment plant ranged from supersaturation to virtual depletion. The dissolved oxygen content at any time depended on the oxidizable material, temperature, sunlight, stream flow, and turbidity, and varied considerably with the seasons, showing the widest variation during periods of high temperature and low flow. Daily maximum and minimum dissolved oxygen values recorded during four representative sampling runs are shown graphically in Figures 4 and 5. Seasonal variations in the dissolved oxygen content throughout the stream have been discussed in detail by the authors in previous papers (1)(2).

Biological Data

Bacteriological studies of Lytle Creek were conducted during the first year of the project. Two indicators of sewage pollution were investigated; namely,

TABLE II.—pH Data,[1] Lytle Creek Surveys

Station	Mar. 14–15, 1950	July 11–13, 1950	Aug. 15–18, 1950	Sept. 28–29, 1950	Feb. 25–26, 1952
8.7	—	—	7.8	—	8.1
7.6	8.3	8.1	8.1	7.9	8.3
Effluent	7.7	7.1	6.8	7.2	—
7.2	8.4	7.2	6.9	7.3	8.1
6.5	—	7.4	7.2	7.5	7.8
5.2	—	7.7	7.9	7.7	7.9
4.2	—	—	7.9	—	8.1
2.8	8.2	—	—	7.9	8.1
1.0	8.3	—	—	7.9	8.2

[1] All samples taken at 12:00 Noon.

coliforms and enterococci. Coliform densities were determined by fermentation tube procedures described in the 9th edition of "Standard Methods for the Examination of Water and Sewage," while enterococcus densities were determined by the Winter and Sandholzer method. "Total" bacterial estimates were based on the "five-tube most probable number" method, using growth (turbid *versus* clear) end points in lactose broth. One set of tubes was incubated at 37° C. and a duplicate set at 20° C.

Sampling runs of 24-hr. duration conducted in December 1949, and March, July, and August 1950, revealed that Lytle Creek above the sewage outfall contained relatively few coliforms and enterococci. Approximately 99 per cent of the coliforms in the stream below the outfall were attributed to the sewage effluent. The two indicator groups showed a rapid death rate in the stream section between the sewage outfall and Station 2.8, approximately four miles downstream. In December and March, "total" bacterial densities, as indicated by samples incubated at temperatures of 37° C. and 20° C., showed a progressive decrease below the outfall. In marked contrast, summer samples incubated for 48 hr. at 20° C. showed nearly consistent in-

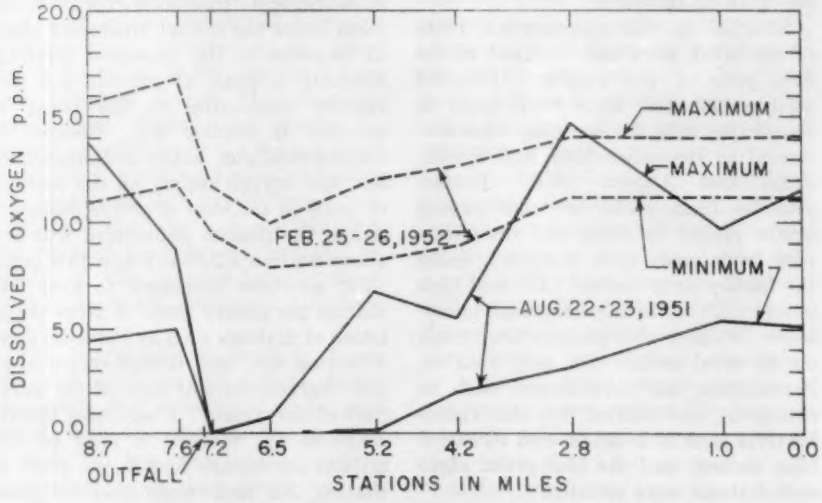

FIGURE 4.—Range in dissolved oxygen, Lytle Creek.

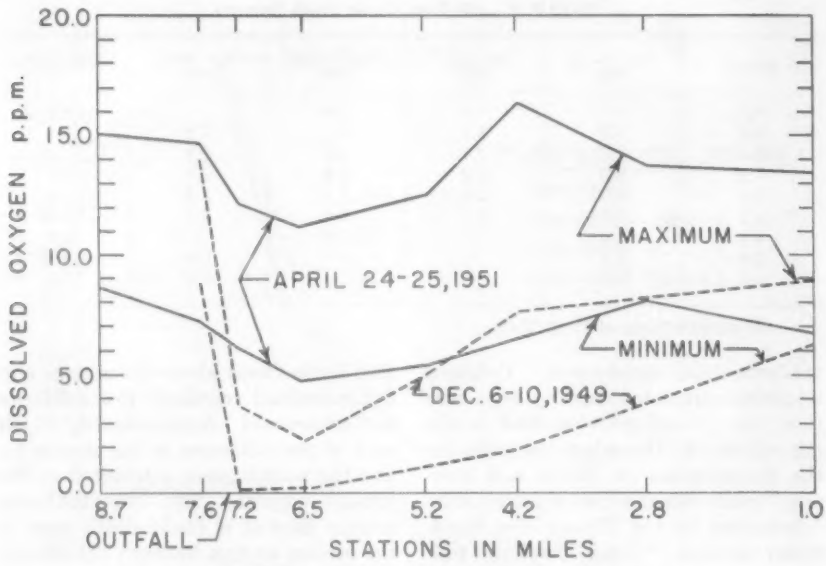

FIGURE 5.—Range in dissolved oxygen, Lytle Creek.

creases in concentration with distance from the sewer outfall to Station 6.5 in July, and to Station 5.2 in August. Tests for coliforms and "total" bacterial growth on the bottoms of the riffles and pools showed consistently higher concentrations of organisms in the riffles than in the pools.

Studies on the microbenthic biota of the creek were also confined to the first year of the project. Detailed analyses of such biota were made in connection with the sampling runs conducted in December 1949, and March, July, and August 1950. Bottom growths from rocks or from paving bricks placed in riffles and mud samples from pools were analyzed, using the Lackey drop method (13) and high power (323 ×) of the compound microscope. Counts of organisms were made on an areal basis. Not only rotifers, crustaceans, and protozoans, such as rhizopods, and ciliates, but also visible bacteria such as zoogloea and *Sphaerotilus natans,* and the blue-green algae and diatoms were counted.

In conducting these studies of the microbenthos, pools and riffles were considered separately. Only the most significant of the trends as revealed by the December 1949 run are considered in this paper. During that month, under low flow conditions, pollution-tolerant blue-green algae, largely *Oscillatoria* spp., increased greatly in the pools below the sewage treatment plant in response to the increased fertility, reaching a peak at Station 6.5 and rapidly decreasing to the point of scarcity at Station 4.2. Because of limited sunlight, heavy sedimentation, and low oxygen supply on the bottoms of pools in the zone of active decomposition, the diatom population was low above Station 4.2; but below this point their numbers increased to over 110 million per square foot. A large population of diatoms such as *Navicula* spp., *Nitzschia* sp., and *Gomphonema* spp., was characteristic of most of the lower part of the stream. Flagellates, chiefly *Euglena* sp., reached a peak of 159 million per square foot in the pools at Station 5.2 and were also in great abundance at Station 2.8.

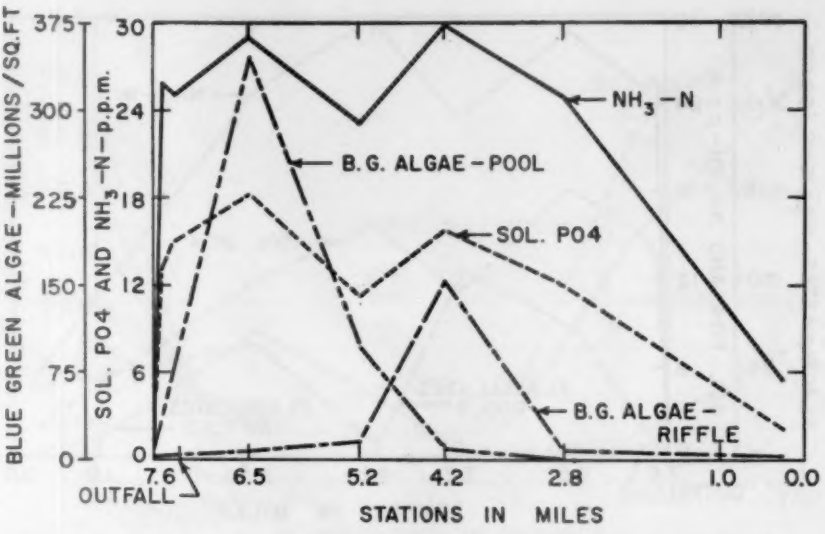

FIGURE 6.—Relation of blue-green algae to nutrients, Lytle Creek, December 1949.

Although flagellates were abundant in the pools from the point of sewage discharge to Station 5.2, very few of them were found in the riffles above Station 4.2. The blue-green algae in the riffles had much the same distribution as the flagellates. The peaks of growth of both groups in their respective habitats corresponded fairly well with high concentrations of ammonia nitrogen and phosphates as determined from the 24-hr. composite samples (Figures 6 and 7). Zoogloeal masses and *Sphaerotilus natans* increased rapidly below the sewage treatment plant, reaching a peak at Station 6.5, below which they decreased rapidly. This decrease was attributed to the reduced food supply and the voracity of the bacteria-feeding rhizopods and ciliates associated with them (Figure 8).

The distribution of bacteria, protozoa, and algae in the stream during December 1949 is believed to be typical of their distribution during other periods of low flow, when definite pollutional zones were observed. As has been previously mentioned, well-defined zones of pollution were present in the stream most of the time from early May to late November or early December each year. By January, however, the increased non-flood flow extended the carpet of *Sphaerotilus* and other bacteria and protozoa characteristic of the septic zone to the formerly clean water zone, three miles downstream. Throughout the period of normal high flows characteristic of the winter months the entire lower section of the stream exhibited pollutional fauna and flora intermixed with clean water forms.

In the Lytle Creek studies emphasis was placed on determinining the role and value of the macro-invertebrates as indicators of pollution. The decision to do this was based on their size and more distinctive morphological characteristics, which facilitate their identification under field conditions. In addition, most representatives of this group have longer life histories than the microbenthic fauna and are thus better fitted for indicating past ecological conditions in any given area.

Intensive qualitative and quantita-

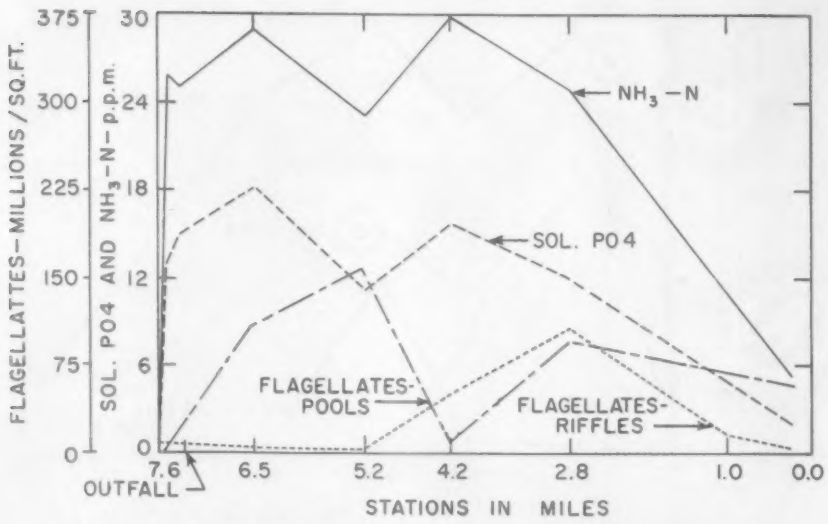

FIGURE 7.—Relation of flagellates to nutrients, Lytle Creek, December 1949.

tive studies of the macro-invertebrate inhabitants of the stream were carried out during all seasons of the year. During the qualitative surveys, conducted in connection with the sampling runs, 144 species representing 110 genera of animals were collected and identified. The studies revealed striking seasonal differences in the numbers of species and faunal associations occurring in the various sections of the stream. The number of species of macro-invertebrates found in different sections of the stream during each of the seasons is shown in Figure 9.

One-third to one-sixth as many spe-

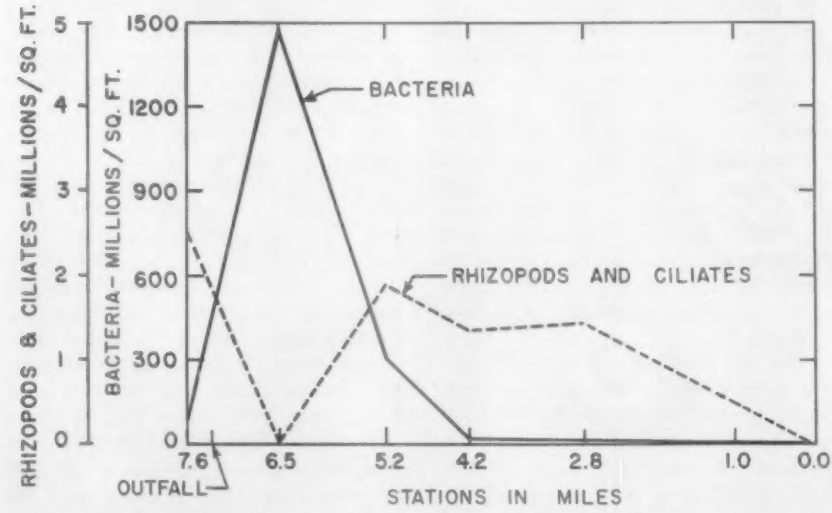

FIGURE 8.—Distribution of bacteria and protozoa, Lytle Creek, December 1949.

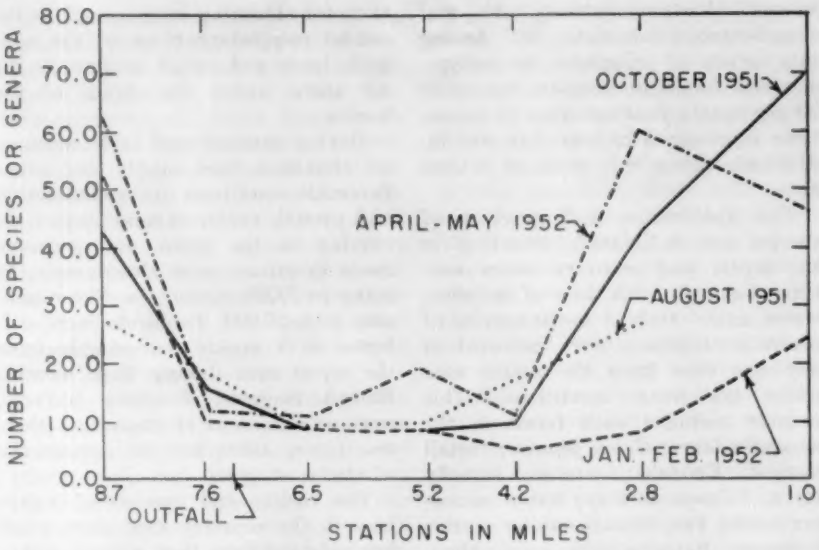

FIGURE 9.—Macro-invertebrate distribution, Lytle Creek.

cies, depending on the season, were found in the septic zone as in the stream above the outfall. This reduction is believed to have been due largely to oxygen depletion during periods of high temperature and low flow and to changes in the nature of the stream bottom. The largest number of species (70) was taken in the lower clean water zone at Station 1.0 during October 1951. The variety and abundance of life present in that section reflect the favorable effects of organic enrichment and relatively constant stream flow during the late summer months.

Analyses of the species composition and abundance of individual organisms in the various zones point to biological phenomena which constitute valuable criteria for evaluating the role and value of such associations as indicators of pollutional conditions in a stream (13)(14)(15)(16)(17)(18)(19)(20)(21). Because the entire stream below the sewage treatment plant was affected to some extent by the effluent which it received, only the two mile section above the outfall displayed what may be considered as clean water conditions at all times. The number and variety of macro-invertebrates occurring in that upper section were typical of the fauna which existed in non-polluted streams in the area.

The fauna at all times consisted of a variety of species representing many different genera, families, and orders of invertebrates. The smallest number of species collected at one sampling was 29, taken in August 1951; the largest number (63) was encountered in April 1952. The latter number, collected at Station 8.7, very well illustrates the diversity of life present. The following species of invertebrates were taken: water fleas (Collembola), 1; true flies (Diptera), 18; beetles (Coleoptera), 13; mayflies (Ephemeroptera), 4; caddis flies (Trichoptera), 6; stoneflies (Plecoptera), 3; dragon flies (Odonata), 4; water bugs (Hemiptera), 3; crayfish and shrimps (Crustacea), 3; snails (Mollusca), 4; segmented worms (Annelida), 1; flat-

worms (Platyhelminthes), 1; and roundworms (Nematoda), 2. Among this variety of organisms, no one species was found in numbers exceeding 50 per square yard, whereas 45 species were represented by less than five individuals per square yard of bottom area.

The distribution and numbers of species and individuals occurring in the septic and recovery zones contrasted sharply with those of the clean water zone. Only 8 to 10 species of macro-invertebrates were collected at any one time from the septic zone under low water conditions. This number included such forms as the mosquito larva, *Culex pipiens;* rattail maggot, *Eristalis bastardi;* horsefly larva, *Tabanus atratus;* water scavenger beetle, *Tropisternis natator;* water boatman, *Hesperocorixa* sp.; pulmonate snail, *Physa integra;* and sludgeworms, *Limnodrilus* sp. and *Tubifex* sp. As many as 18 species were taken from that section in the spring when the flow was high. However, 8 of that number were drift forms traceable to a nearby tributary.

Of the 8 to 10 species of macro-invertebrates occurring in the septic zone during the late summer and autumn, not one species was restricted to that section of stream. All occurred, but in far smaller numbers, in both the recovery and clean water zones. In these latter areas, however, they were very restricted in their distribution, being largely confined to quiet water micro-habitats having dissolved oxygen, food supplies, and bottom conditions similar to those which existed in the septic zone.

Analysis of the macro-invertebrate population characteristic of the septic zone in August 1951 reveals that 40 per cent were Diptera, 20 per cent Coleoptera, 20 per cent Annelida, 10 per cent Hemiptera, and 10 per cent Mollusca. All of the insects generally found in this zone were characterized by the possession of special adaptations for obtaining oxygen, such as the caudal respiratory tubes of the mosquito larva and rattail maggot, or the air space under the elytra of the beetles.

During summer and early autumn, an abundant food supply and other favorable conditions for reproduction and growth enable several species occurring in the septic and recovery zones to attain great abundance. As many as 3,000 mosquitoes, *Culex pipiens,* and 20,000 Tubificids were collected in a square foot sample from the septic zone during these months. Rattail maggots, *Eristalis bastardi,* were so numerous at times that their respiratory tubes had the appearance of blades of grass.

The variety and number of organisms in the recovery zone were much less constant than they were in either the clean water or septic zones. Environmental conditions ranged from near septicity in the upper end of the recovery zone to practically clean water in the lower portion. The limits of the zone also shifted frequently with the seasons and change in flow. The least number of species encountered in the middle section of the recovery zone was 9, found in October 1951; the greatest number was 32, collected in April 1952. During the former month the fauna consisted of species typically found farther upstream, while during the latter month the fauna was more typical of clean water conditions. The community of organisms encountered in April included seven species of relatively sensitive mayflies, stoneflies, and caddis flies which apparently had drifted into the main stream from tributaries. Each of these species had been able to survive in numbers up to five per square yard. Such seeding of additional fauna did not occur in the autumn of 1951 when all the tributaries were dry.

Analysis of the distribution of the major groups of aquatic macro-invertebrates in the stream reveals

that no association was made up entirely of clean water representatives. The mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddis flies (Trichoptera), all gilled forms, were more nearly restricted to and comprised a larger portion of the clean water association than any of the other groups. Members of these orders and other gill breathing immature insects scattered through several orders, were most affected and restricted in their distribution by the very low dissolved oxygen concentrations often present in the polluted zones.

There are, however, exceptions. Two species of mayflies, *Stenonema femoratum* and *Callibaetis* sp., were taken on several occasions in sections of the recovery zone where the dissolved oxygen content was reduced to as low as 1 p.p.m. at night. It is possible that the oxygen concentrations in the niches occupied by the two species, of which the former occurred in the fastest riffles and the latter in marginal or shoal areas, where the water was less than 6 in. deep, were higher than the value recorded for the stream section. However, both species displayed much greater tolerance to low oxygen levels than has heretofore been thought possible (22).

Further, representatives of one family of Trichoptera, the net building *Hydropsychidae,* also were found commonly in areas where the oxygen supply at night was often reduced to less than 3.0 p.p.m. In all such cases, however, the larvae or pupae were located in the most rapid portions of riffles where they could obtain the maximum available supply of oxygen as well as food.

With only two exceptions the stoneflies were entirely restricted to clean water areas. *Allocapnia viviparia* and *Perlesta placida* were taken both as nymphs and adults in limited numbers from the upper recovery zone of the stream during the winter and early spring months when conditions were temporarily favorable for their existence. The minimal dissolved oxygen value recorded during the period when they were collected was 7.8 p.p.m. All evidence indicated that they were contributed to the main stream from nearby tributaries where they occurred in large numbers. Since both species pass through the summer and early fall in either the egg stage or as very small inactive nymphs, it is debatable whether or not they could have lived and completed their earlier development in the stream proper when much lower dissolved oxygen levels existed.

While there are exceptions, such as those just considered, in general an association of mayflies, stoneflies, and caddis flies in a stream is indicative of clean water conditions, and their absence often denotes the presence of pollution and/or a low oxygen supply if the physical nature of the habitat is otherwise suitable. Usually the presence or absence of representatives of other orders of aquatic insects which breathe by gills, and which are, therefore, dependent upon oxygen dissolved in the water for their respiratory needs, has similar indicator significance. For example, while most aquatic beetles can renew their oxygen supply directly from the atmosphere and are thus unaffected by oxygen-depleting wastes, the larvae, pupae, and adults of those species which are entirely aquatic are dependent upon dissolved oxygen and are restricted to clean water streams which are well aerated. In Lytle Creek several species of riffle beetles, such as *Stenelmis crenata* and *Stenelmis sexlineata,* were found only in the upper and lower clean water zones. Their distribution in the stream indicates that the family, Elmidae, to which they belong, is a member of the clean water association.

While most gill-bearing aquatic insects are limited in their distribution by low dissolved oxygen supplies, some forms which have more than one means of respiration, such as the dragonflies

and damselflies, display considerable tolerance to low levels of dissolved oxygen. Their greater adaptability to environments low in dissolved oxygen is made possible by the possession of respiratory structures which are the most highly developed of the various gill systems (22). These insects can carry on respiration by means of four different structures; namely, (1) caudal tracheal gills; (2) rectal folds; (3) the integument; and (4) spiracles. Since all four organs may function at the same time and many of the stream forms occur in either riffles or shallow marginal areas, the group is remarkably well-adapted to withstand the oxygen depleting effects of organic pollution. As a result of this adaptability, the nymphs of both dragonflies and damselflies were often taken in Lytle Creek in sections of the recovery zone where the dissolved oxygen supply during the summer was as low as 1.0 p.p.m. for a short time during the night or in the early morning hours.

In Lytle Creek insects of the orders Hemiptera, Coleoptera, and Diptera had the most varied representation, were the most widespread in their distribution and were least affected by dissolved oxygen concentration. Representatives of these orders were found in all stream habitats representing all degrees of pollution and stream recovery. Some species from each group were found fairly widely distributed through the stream; others, while not restricted to either a clean water or polluted area, showed by their abundance a strong preference for one or the other type of habitat. Still other species, particularly among the Diptera, were restricted to clean water or to water rich in organic materials.

Of the three orders, the Hemiptera and Coleoptera were the poorest indicators of organic pollution and oxygen depletion in the stream. With the exception of the Elmidae, or riffle beetles, other species of beetles and all of the species of water bugs collected were found throughout the stream, usually occurring most abundantly in the polluted areas where they found an abundant food supply. The ability of members of these two orders to withstand the oxygen-depleting effects of organic pollution is due to special modifications of their tracheal system. These modifications serve to increase the internal air capacity of the tracheal system, supplement tracheal diffusion by ventilation movements when the insects come to the surface for air, and provide supplementary external air stores. Common to all of these forms are the modification of the body surface for breaking the water surface film, and changes in the wings and body surface for capturing and holding stores of air, and in the tracheal system for surface ventilation and connection with the external air stores. In oxygen-deficient waters members of these two groups have only to increase the frequency of their visits to the surface to cope with decreasing oxygen supplies.

The efficiency of these modifications for obtaining and storing atmospheric oxygen is well illustrated by *Dytiscus*, one of the diving beetles. Reeder (22) reports that this beetle can remain submerged for 36 hr. without coming to the surface to renew its oxygen supply. To obtain a supply of oxygen *Dytiscus* breaks the surface periodically with hydrofuge hairs, and ventilates violently by means of accessory respiratory muscles. The fore wings, elytra, have a locking mechanism to trap the atmospheric air, and the abdominal and thoracic spiracles are displaced so as to open into this respiratory air store.

Aquatic Diptera were found in the stream in many different ecological niches in both the clean water and polluted zones. However, with the exception of only a few species, representatives of this order were highly selective in their choice of habitat. A number of species such as *Diamesa nivoriunda*,

Cricotopus absurdus, and *Calopsectra neoflavella,* were found only in the cleanest, most highly aerated sections of the stream, while others such as the mosquito, *Culex pipiens,* and rattail maggot, *Eristalis bastardi,* while found in limited numbers in clean water areas, showed a decided preference for the polluted sections. The variability in choice of habitat and in the range of distribution of the species taken was determined largely by the food-getting and respiratory requirements and adaptations of the different individual species. The larvae and pupae of the mosquito and rattail maggot, with their special respiratory tubes, were unaffected by low oxygen supplies, as evidenced by the extremely large numbers of each taken in the most septic areas. Certain red-blooded Chironomids, such as *Chironomus riparius,* also demonstrated a remarkable ability to thrive in the septic and recovery zones. Walshe has shown that the hemoglobin possessed by midge larvae such as *Chironomus riparius, Chironomus plumosus,* and closely related species, apparently acts in both the transportation and storage of oxygen (23) (24). Its greatest transport role is during anaerobiosis, when it permits the larva to continue filter feeding in low oxygen tensions and thereby increases the rate of recovery from exposure to such conditions.

As in the case of the insects, the other groups of macro-invertebrates in the stream showed considerable variation in their distribution and adaptability to varying degrees of pollution. Certain groups such as the sludge worms, Tubificidae, were found in very large numbers in bottom sludges of high organic content in the lower end of the septic zone and the upper end of the recovery zone. Their numbers were found to decrease rapidly as the nature of the bottom sediments changed. The ability of two genera of these worms, *Tubifex* and *Limnodrilus,* to utilize the rich supply of organic material in the polluted zones, under practically anaerobic conditions, made them important and conspicuous members of one of the stream's most characteristic pollutional communities.

Another species of invertebrate which occurred throughout the stream, but which formed a large and conspicuous component of the most common pollutional association in Lytle Creek, was the pulmonate snail, *Physa integra.* The ability of this species to obtain atmospheric oxygen directly enabled it to take advantage of the abundant food supply in the polluted zones. As a result, this species was several hundred times as abundant in the pollutional enriched areas as in the clean water sections. The mere presence or absence of this species in a given area is a poor criterion of organic pollution and oxygen depletion, but when its mode of occurrence, relative abundance, and faunal associates are considered, its index value as an indicator of the degree and extent of organic enrichment in Lytle Creek was very great.

Discussion

Some investigators, such as Kolkwitz and Marsson (20)(21), Weston and Turner (5) and Richardson (19), have attempted to associate definitely individual species with different degrees and types of pollution, and have published lists assigning such species to different zones or subzones of pollution. Careful comparison of these different lists will show that there is an appreciable lack of agreement as to the true status of many of the organisms. A species which one worker may list as being characteristic of polluted water may be reported by others as being found only under clean water conditions.

It is apparent that there has been an oversimplification of the problem by the supplying of lists which might be used by many without adequate investigation of the clean water commu-

nities. There are several reasons for the lack of agreement in the different lists. Perhaps foremost is the fact that, in making use of such environmental classifications for the setting up of lists, little reliance can be placed upon the mere occurrence of a single species in a given locality (19)(26). Many organisms which occur in large numbers in extremely polluted water also are found in limited numbers in cleaner situations. For example, all of the species of invertebrates which occurred in the septic or recovery zones of Lytle Creek were also found in limited numbers in similar microhabitats in the clean water zones. Conversely, many aquatic organisms that are intolerant of persistent organic pollution can live for a short period of time in a polluted area when pollutional effects are at a minimum. Such occurrences were particularly evident in Lytle Creek during periods of high flow in the winter and spring months when temperatures were low and dissolved oxygen concentrations were high. Under such conditions several species of mayflies, stoneflies, and caddis flies, which drifted into the septic and recovery zones of the stream from nearby tributaries, were able to remain alive for periods sufficient to allow them to emerge as adults. In all such instances, however, the numbers of such clean water forms were distinctly limited when compared with the populations of organisms usually found in the stream.

A second reason for the lack of agreement as to the indicator value of certain aquatic organisms is that several environmental factors other than the presence of a pollutant may affect or limit the distribution of certain species (25). Chief among these are geographical location, erosion, floods, the size of the stream, the type of bottom, and the flight range of the insect. Species lists compiled for one section of the country or world may be of little value in another region, because of the fact that many aquatic organisms are very restricted in their distribution. In order for any comprehensive list or grouping of indicator organisms to be applicable to all sections of the country, the pollutional status of typical aquatic organisms throughout the country must be studied and such information incorporated into the list.

Type of bottom, speed of current, depth of water, and many other factors affect the distribution of the stream fauna in any given section. Due to the differing physiological requirements and morphological adaptations of aquatic organisms, the populations found in soft muck, sand, or gravel bottoms, and in riffles, pools, and marginal areas are quite distinct.

A third major reason for lack of agreement among lists of indicator species is the absence of keys and descriptions for the fauna in many areas and want of sufficiently distinct morphological characteristics to provide for species separation. Because of considerable lack of agreement which exists concerning the pollutional status of many aquatic organisms, little reliance can be placed, at the present time, upon the occurrence of a single species as an indicator of pollution. In evaluating the reliability of aquatic organisms as indicators of pollutional conditions, one must consider the different indicator organisms not separately, but as biological associations or populations. The authors believe that the organisms should be considered in groups according to their morphological adaptations and physiological requirements. This became very evident during the course of the Lytle Creek studies and has led them to the conclusion that few definite statements can safely be made concerning the indicator value of the mere occurrence of specific organisms in the stream. However, fairly definite conclusions can be formulated as to the value of certain associations of aquatic inver-

tebrates for indicating degrees of organic pollution in the stream.

In general, the community of aquatic invertebrates that was most characteristic of the septic zone in Lytle Creek consisted of such pollution tolerant organisms as sludge worms, *Tubifex* spp. and *Limnodrilus* spp.; pulmonate snails, *Physa integra;* rattail maggots, *Eristalis bastardi;* mosquitoes, *Culex pipiens;* and midge larvae, *Chironomus riparius.* All of these species occurred in large numbers during the summer and early autumn. During the winter months, only the sludge worms, pulmonate snails, and midge larvae were commonly represented. In addition to the several species mentioned, the association of organisms in the septic zone, particularly during the summer months, included limited numbers of diving and water scavenger beetles, *Laccophilus maculosus* and *Tropisternus natator;* whirligig beetles, *Dineutes americanus;* and various species of Hemiptera, such as *Corixa* spp., *Gerris* spp., and *Belostoma* spp. Since all of these species of beetles and water bugs obtain their oxygen supply directly from the atmosphere and are largely confined to the surface or marginal areas of a stream, they were distributed in fairly uniform numbers throughout Lytle Creek. Their presence, then, cannot be regarded as having any index value for the degree of oxygen depletion.

In the recovery zone the population of invertebrates varied from septic associations at the upper end of the zone to practically clean water communities in the lower section. The community of organisms most characteristic of average conditions in the recovery zone consisted of lesser numbers of the species found in the septic zone plus variable numbers of the more tolerant clean water species. The latter group included a variety of invertebrates. The most common of these species were blackfly larvae and pupae, *Simulium vittatum;* dragonfly nymphs, *Libellula lydia;* midge larvae and pupae, *Pelopia stellata;* mayfly nymphs, *Callibaetis* sp.; and caddis fly larvae and pupae, *Cheumatopsyche* sp.

In the clean water zones there was a great variety of invertebrate communities, each consisting of many different species. With ecological conditions less restrictive, and greater competition for food and space existing between the different organisms that made up the population, no one species was able to increase in numbers and be represented by the large numbers of individuals characteristic of the septic zone. Each community was a dynamic unit, consisting of herbivores, carnivores, and omnivores; prey and predators; lung, tracheal tube, and gill breathers. Each organism was adapted to its own ecological niche and offered check reins against too rapid growth or reproduction of the others. Most of the species which occurred in the septic and recovery zones were also found in very limited numbers in the clean water zones. In addition, there was also present a wide variety of forms which were intolerant of conditions in the polluted zones. Most of these were the gill-breathing, immature stages of such insects as the mayflies, stoneflies, caddis flies, and alder flies, plus clean water representatives of the other groups of aquatic invertebrates.

In considering the distribution of organisms in the stream, those species of aquatic invertebrates which obtain their oxygen supply by means of gills only, with the exception of *Callibaetis* sp., *Stenonema femoratum, Cheumatopsyche* sp., and *Allocapnia viviparia,* were found to be most sensitive to the organic pollution in Lytle Creek. With those exceptions, all strictly gill-breathing forms were restricted, by the oxygen depleting effects of the organic wastes, to the clean water zones of the stream. They constituted the principal members of the varied communities characteristic of the clean water areas.

By contrast, all of the invertebrates which occurred most commonly in the polluted zones had special adaptations for obtaining atmospheric oxygen or had low oxygen requirements. With such adaptations, depletion of oxygen in the water did not serve as a barrier to their distribution.

In conclusion, pollution of Lytle Creek by organic wastes was only one of several environmental factors determining the composition of the aquatic populations. Before any definite conclusions concerning the effects of organic pollution on the stream's biota could be drawn, it was necessary to consider such factors as variations in flow and water temperatures, the nature of the watershed, the type of bottom, the life histories of the organisms concerned, the drift of organisms downstream, seeding from tributary streams, and the morphological adaptations and physiological requirements of the organisms. Only after considering all these factors was it possible to arrive at the various conclusions stated in this paper.

Summary

Intensive studies were carried out on Lytle Creek to discover the effects of sewage pollution on the aquatic communities of the stream and the value of these populations as indicators of present and past pollutional conditions. In these investigations physical-chemical conditions were related to the qualitative and quantitative composition of the aquatic populations in the different life zones.

The distribution and abundance of bacteria, protozoa, and algae in the stream were largely determined by nutrients and predator-prey relations. Approximately 99 per cent of the coliform bacteria in the stream below the sewage outfall were contributed by the sewage. In the first two miles of stream below the outfall, coliforms and enterococci decreased, whereas the total bacterial population increased. Zoogloea, *Sphaerotilus*, and certain protozoa were most abundant in the section immediately below the sewage outfall while pollution-tolerant blue-green algae increased progressively in the pools for a distance of two miles downstream with the diatoms reaching their peak below this section.

Seasonal diurnal changes were great and were most marked in the recovery zone. Diurnal fluctuations in dissolved oxygen and pH were greatest in late spring and early summer.

Very few definite statements can safely be made concerning the indicator values of specific organisms, but definite conclusions can be formulated as to the value of certain associations or populations of aquatic invertebrates for indicating the severity and extent of pollution and the degree of stream recovery.

Little reliance can be placed upon the mere occurrence of a single species in a given locality. In Lytle Creek the 9 species characteristic of the septic zone also occurred in the recovery and clean water zones, but in much smaller numbers. The distribution and number of species and individuals in the septic zone differed greatly from that in the clean water areas. The septic zone had less than one-fifth as many species as the clean water zone, but the number of individuals of each species and the total number of organisms per unit area were many times greater. The septic zone was characterized by species adapted to live under low D.O. conditions (less than 1 p.p.m.) as *Tubifex* and *Limnodrilus*, or those able to secure their oxygen directly from the air as do *Culex pipiens, Eristalis bastardi*, and *Physa integra*. Hemiptera and Coleoptera were found in the septic zone, but these were also equally numerous in other zones. The modification of their tracheal system and general body surface which increases the internal air capacity of the tracheal system and enables them to use external air stores which serve like

physical gills, enabled them to withstand very low D.O. levels (1 to 0.5 p.p.m.), and made their mere presence a poor indicator of dissolved oxygen content.

The community of organisms most characteristic of average conditions in the recovery zone consisted of lesser numbers of the species found in the septic zone plus variable numbers of the more tolerant forms found in clean water, especially those having a variety of methods for securing oxygen. These included certain larvae of the blackfly, *Simulium vittatum;* midge, *Tanypus stellatus;* and caddis fly, *Cheumatopsyche* sp.; and nymphs of the mayfly, *Callibaetes* sp., and dragonfly, *Libellula lydia.*

Clean waters were characterized by a great variety of invertebrate communities consisting of herbivores, carnivores, and omnivores; prey and predators; lung, tracheal tube, and gill breathers. In general a population containing abundant gill-breathing forms, mayflies, stoneflies, and caddis flies was indicative of clean water conditions and their absence denoted the presence of pollution and/or low oxygen.

Acknowledgments

An investigation of this type requires the services of a considerable number of people. Several members of the Bacteriology Section and the Chemistry and Physics Section cooperated actively in the project during the first year. The Bacteriology Section made the various bacteriological determinations; the Chemistry and Physics Section made the B.O.D., nitrogen, and phosphate determinations. The entire staff of the Biology Section has assisted in certain phases of the study, and their contributions are gratefully acknowledged. Special thanks are extended to the following people for help in the identification of specimens: George Paine of the Center, Diptera; Harold Walter, University of Michigan, Mollusca and Oligochaeta; John N. Wilson, Pacific Northwest Drainage Basin, Micro-benthos; Dr. Herbert H. Ross, Illinois Natural History Survey, Trichoptera; Dr. Milton Sanderson, Illinois Natural History Survey, Elmidae; Dr. Frank N. Young, Indiana University, Coleoptera; Dr. Willis W. Wirth, U. S. National Museum, Diptera; Dr. Speed Rogers, University of Michigan, Tipulidae; Dr. George H. Bick, Tulane University, Odonata; and Dr. E. M. Walker, Royal Ontario Museum of Zoology, Odonata.

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JOURNAL BACK NUMBERS

A grateful word of thanks is due to those who have responded so promptly to our recent appeal for Journal back numbers. Their cooperation is sincerely appreciated.

We are still short copies of the January 1955 issue of SEWAGE AND INDUSTRIAL WASTES, however, and would like to receive any copies of this issue with which the owners are willing to part. Reimbursement is at the rate of $0.50 per copy plus postage.

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THE OPERATOR'S CORNER

CONDUCTED BY DONALD P. SCHIESSWOHL

HATFIELD AWARDS

The William D. Hatfield Award of the Federation was established in 1946 to recognize operators who had prepared outstanding annual sewage and industrial waste works operation reports. The award was established to encourage operators of sewage treatment plants to prepare, publish and distribute annual operating reports which are necessary or desirable for the following purposes: *

1. To serve the interests of public relations.
2. To provide a means whereby the operator may make a businesslike accounting of the expenditure of funds and care of the treatment plant and accessories entrusted to him.
3. To serve the report requirements of the operator's superior officials.
4. To serve generally as a basis for recommendations made by the operator for improvements to his plant to secure better efficiency and economy of operation of higher degrees of treatment.
5. To advance the art and knowledge of sewage and waste treatment through making available to other engineers and operators the basic information and data concerning operation of a particular plant which is needed for study or appraisal purposes as related to proposed new developments or changes in operating procedures or methods elsewhere.

To recognize worthy operation reports presented a tremendous task to the Plant Operation Committee. Another difficulty was that operators apparently felt that the competition was unfair in that well-financed facilities were pitted against others that were struggling to make every dollar do double duty. Response to the competition declined, resulting in the suspension of the award in 1952, 1953 and 1955.

Recognizing that the award had merit but was not serving its intended purposes, the 1955 Federation Board of Control considered a report by the Plant Operation Committee which recommended that the number of awards be increased and local competition emphasized. The Executive Committee was empowered to adopt a new basis for making the award. The adopted award schedule (THIS JOURNAL, **28**, 1, 118; Jan., 1956) is identical to the recently revised (1954) Bedell Award schedule. Competition is now among fellow operators; operators who are members of the same association, have similar interests, operating conditions and aims.

Each Member Association should have a Hatfield Award Committee (if not in name at least in function). In addition to its function in the selection of the Association's Hatfield Awardee, the committee would be the operator's committee to stimulate operator interest in the Association and Federation activities. It is hoped that the revised schedule will instill new interest in the Award and that Member Associations will recognize this as an opportunity to encourage operator interest in better sewage treatment plant operation.

D.P.S.

* THIS JOURNAL, **22**, 1, 137 (Jan., 1950).

ACCELERATED SLUDGE DIGESTION EXPERIENCE AT COLUMBUS, OHIO *

By James H. Blodgett

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Much progress has been made during the past 25 years in the improvement and simplification of sewage treatment. Much has been done and many facts have been recorded concerning the various processes and methods of accomplishing the desired improvements in clarification and purification.

It is, of course, well known that clarification and purification of sewage is but one phase of the problem of sewage treatment. Another phase, that of disposing of the solids removed and collected during clarification, is of equal importance and in some ways, more complex and difficult to perform.

The first cost of providing facilities for the collection and disposal of sewage solids is a sizeable item in the overall plant expenditure. Furthermore, operational cost of these facilities in plants over 10 m.g.d. will equal or exceed one-half the total cost of sewage treatment. Therefore, improvements in the methods of sludge disposal are of great interest to the profession.

The trend from two-compartment sludge digestion tanks, providing settling, solids digestion and storage in one unit, to separate units, one for settling out solids and one for digestion and storage, has improved the efficiency of the process insofar as sludge disposal is concerned. The process of solids reduction through digestion is thus made easier to control through the use of optimum digestion temperatures. Heating speeds up the digestion process, thereby reducing digester tank volume requirements, since the size of the digestion unit is dependent upon the length of time required to reduce the solids to comparatively inert material. Conventional standards for digesters require from 30 to 45 days at 90° to 95° F.

Other factors of course enter into the question of the size of digester, such as storage capacity for digested solids, where this is required. However, the major consideration is the space required for active destruction of the solids placed in the digestion tank.

The primary purpose of this paper, is to present the operating experiences with a process that directly affects the capacity of digestion tanks,

Columbus was among the pioneers in the application of separate sludge digestion to the process of sewage treatment. In accordance with the best information available at that time (1930), the sludge digestion tanks were designed and built on the basis of 30-days detention at 90° to 95° F. The loading rate was computed at .1 lb. of dry solids per cubic foot of maximum tank capacity per day. This loading was to be obtained from a mixture of primary sludge and excess activated sludge, the latter to be concentrated by means of centrifuges and added to the raw sludge in a collection well.

Unfortunately, the centrifuge method of concentration of activated sludge did not prove practical and as a consequence, the plant has been operated by returning the excess activated sludge to the primary tanks. This method of disposing of the activated sludge has adversely affected the plant operation, due to carry-over of

* Presented at 1955 Annual Meeting, Pennsylvania Sewage and Industrial Wastes Assn.; State College, Pa.; Aug. 22–24, 1955.

TABLE I.—Sludge Digestion Data with Conventional Digester Operation

Year	Raw Sludge Solids (%)	Tank Load (lb./cu.ft./cap. per day)	Vol. Solids (%)	Detention (days)	Gas (cu.ft. per lb. vol. add.)	Vol. Solids Red. (%)
1941	5.0	0.117	65.9	27	6.5	37.1
1942	4.8	0.12	65.7	25	5.8	36.0
1943	5.0	0.10	65.6	32	6.7	39.5
1944	5.3	0.10	68.3	33	7.4	43.0
1945	4.9	0.098	67.0	31	6.0	40.5
1946[1]	4.5	0.091	67.3	31	6.2	42.0
1947	4.3	0.087	65.0	31	5.9	37.3
1948	3.7	0.076	64.0	31	4.1	34.0
1949	4.3	0.10	66.0	28	5.7	35.5
1950	5.7	0.112	61.0	32	4.6	36.0
1951	5.5	0.122	57.6	28	6.0	40.0
1952[2]	6.4	0.058	55.6	40	8.2	41.5
1953	6.6	0.06	57.7	65	7.4	45.5
1954	6.7	0.065	57.0	72	6.8	35.0
Avg.	5.6	0.093	63.1	30[3]	5.9[3]	38.2[3]

[1] Based on 10 months of operation.
[2] New additional digesters placed in service.
[3] Based on first 11 years.

excess activated sludge solids from the primary clarifiers as a result of a short detention time. This method of concentration and removal of excess activated sludge has resulted in a lower solids content of the primary sludge. The combined mixture of raw and activated sludge in the sludge digester has precluded obtaining a satisfactory supernatant. In addition, the solids content of the digested sludge, as drawn from the tanks, has been consistently lower (1.5 per cent) than that introduced into the digester.

By 1948, the increased sewage flow and accompanying solids load coming into the plant necessitated expansion of the sludge digestion facilities. As a consequence, in 1951, additional digestion tanks were constructed which increased the available capacity by 140 per cent.

These units were placed in operation in 1952, thus providing ample sludge digestion capacity and detention periods up to 60 days. The increase in detention time did not produce a substantial increase in gas production and a decrease in volatile solids as had been expected.

Table I lists the salient data on the yearly averages for conventional digestion for a period of 14 years.

It should be noted in examination of this tabulation, that the sludge digestion tanks have been consistently loaded to their design capacity with a slight decrease in average loadings during 1947 and 1948, when construction work in progress on other units prevented full-scale operation.

Another interesting fact is the gradual trend toward lower volatiles in the sludge and the increase in percent of solids. This reflects the increase in the flow of industrial wastes which resulted from a population increase of approximately 25 per cent and expanded industrial activities during the past 10 years.

It should also be noted that the effect of placing the new sludge digesters in operation is quite apparent in the loading rate and detention time. However, gas production and volatile solids reduction were not affected proportionately.

Due to the continuing rapid increase in population and sewage flows, the city of Columbus began looking to the future needs in sewage treatment facilities, with a view to the possibility of expanding the present treatment plant or constructing a second plant. Realizing the need for additional digestion tanks, along with other units, it was natural to consider any economical and satisfactory device or process which might reduce expenditures.

As the result of an extended laboratory-scale experimentation and studies on the effect of diffusing digester gas through digesting sludge which were undertaken during 1952 (1), and from the experiences of Morgan (2) with his studies and experiments on a pilot-plant at Iowa City, the city of Columbus decided to proceed with the installation and testing of the "Catalytic Reduction Process" of accelerating sludge digestion.*

One of the original sludge digesters, which, upon the completion of the new digesters had been taken out of service and thoroughly cleaned and inspected, was selected for the test installation. This digester is of reinforced concrete with a fixed cover, 70 ft. in diameter with a sidewall water depth of 25 ft. and a conical bottom approximately 8 ft. deep. The maximum liquid capacity is 106,000 cu. ft. and the tank is equipped with wall hung heating coils. Water which is used to cool the large gas engines in the power plant is circulated through these coils for heating purposes. Unfortunately, the capacity of the original heating system was insufficient to maintain as high a temperature in the digester, particularly during cold weather, as desired. The average temperature in the winter ranged from 80° to 84° F. and from 90° to 95° F. during part of the summer.

* Proprietary process of the Chicago Pump Company, Chicago, Ill.

The equipment necessary to convert the tank to handle the new process is quite simple. It consists of a pipe connection made to the gas dome located in the center of the tank roof; this pipe delivers the gas to a positive displacement type compressor. The compressor, rated at 70 c.f.m. at 12 p.s.i., is driven by a 5 h.p. motor. The discharge from this compressor is piped to the digestion tank through a line which extends vertically down through the center of the tank and terminates in a plenum chamber. This chamber is circular in shape and attached thereto are ordinary air diffuser tubes extending radially. The area of gas diffusion is circular in shape and approximately 6 ft. in diameter. A condensate trap and a flame trap on the intake to the compressor and a flame trap and orifice meter on the discharge line complete the essential equipment required for the installation.

The raw sludge is fed into the center of the digester at a point about halfway down to the plenum chamber and into the rising column of gas and liquid. Batches of sludge are pumped daily from the main sludge collection well in the plant. Digested sludge is withdrawn at the apex of the conical bottom through the original digested sludge lines on the tank bottom. Gas collection is by means of the original gas piping system although it was necessary to install a larger gas meter to measure the increased volume of gas produced by this process. The process was placed in service in May 1953 and has been in full-scale operation continuously since that date.

Since the average loading on the conventional digestion tanks had been approximately 9,000 lb. per day, every effort was made to keep the loading on this tank at three times that load or between 27,000 and 30,000 lb. per day.

Daily samples of primary sludge are

TABLE II.—Summary of Accelerated Sludge Digestion, 1953–1955.

Year	Sludge Solids (%)	Tank Load (lb./cu.ft./cap. per day)	Vol. Solids (%)	Detention (days)	Gas (cu.ft. per lb. vol. add.)	Vol. Solids Red. (%)
1953[1]	6.6	0.29	57.7	14	6.2	39.6
1954	6.7	0.28	57.0	15	6.2	37.0
1955[2]	6.6	0.23	59.3	17	5.9	41.0

[1] Process started May 1953.
[2] Average of six months.

composited and analyses run on the composited sample once a week. The laboratory then advises the sludge control section of the average solids content for the previous week and this is used to compute, in terms of volume, the daily tank level necessary to accomplish the desired loading. The tank level is indicated by a float arrangement hooked to a sight-gauge mounted on the top of the tank.

The tank is operated on a fill and draw basis, with equal volumes of raw sludge and digested sludge being transferred to and from the unit each day. Gas diffusion is continuous and at a rate of a constant 75 c.f.m. This keeps the digester contents in a continuous state of agitation. There is neither stratification of tank contents nor formation of supernatant. Thus when 50,000 or 60,000 gal. of raw sludge are pumped to the digestion tank, an equal amount must be withdrawn as digested sludge to keep the tank level approximately uniform.

Solids loadings as high as 60,000 to 70,000 lb. per day have been placed in the tank occasionally when the concentration of solids in the primary sludge increased above the average for the week's period on which the loading was based. For example, the loading for the current week, based on the average solids analyses of the raw sludge for the previous week, is 5 per cent solids. Then the volume of liquid required to produce the desired loading is established and pumped into the tank each day. However, analyses of the daily samples of raw sludge for the current week may show on one day a solids content as high as 9 per cent which indicates that on that day an 80 per cent overload was applied. Nevertheless, except for an increased gas production on that day or within a day of the excess loading, no indication of upset ever occurred in the tank.

Weekly samples from the digestion tank are analyzed for volatile acid content, and this is the principal control indicator. When there is gradual increase in the amount of volatile acids during a period of four weeks or more, the loadings are reduced in proportion to the increase. If the volatile acid content reaches 800 to 1,000 p.p.m., the digestion tank is allowed to rest until the volatile acids concentration is reduced to 500 p.p.m. or less, and then feeding is resumed. This is the only attention required of the process, except to properly maintain the mechanical equipment and keep the volume of diffused gas constant.

The results of operation of the process are shown in Table II.

Comparison of Table II with Table I shows that with the same sludge placed in both the conventional and the accelerated digestion tank, the latter has handled 2½ to 3 times more solids in approximately one-half the detention time.

The resulting reduction in volatiles is comparable to that obtained in the conventional digestion tanks. Gas production per pound of volatiles added is 6.1 cu. ft. as compared with 5.9 cu. ft. for the conventional digestion process. The accelerated digestion was

TABLE III.—Comparison of Per Cent Solids in Digested Sludge

Year	Per Cent Solids in Digested Sludge	
	Conventional Digestion	Catalytic Process
1943	3.7	—
1944	3.4	—
1945	3.5	—
1946	3.4	—
1947	3.4	—
1948	2.9	—
1949	3.3	—
1950	4.2	—
1951	4.6	—
Avg.	3.8	—
1952	6.1	—
1953	6.6	4.3
1954	5.8	4.9
1955[1]	6.3	5.6
Avg.	6.1	4.9

[1] Average of six months of operation.

accomplished at temperatures of 10° to 15° F. less than those maintained in the conventional tanks.

As previously mentioned the per centage of solids in the digested sludge removed from the conventional digestion tank was consistently lower than that in the sludge introduced. This is thought to have been caused by one of the following three factors or a combination of all three:

1. Liquefication of solids.
2. Effect of mixing primary and excess activated sludge.
3. Admission of ground water through valves located immediately adjacent to the sludge draw-off point.

Table III presents a comparison of the solids content of the conventionally digested sludge, as determined for several years of operation, with the solids content from the accelerated digestion process. Increasing the detention period from an average of 30 days to 60 or more days and blocking off the ground water valves previously mentioned, has resulted in less differential between the solids content of the raw and digested sludge handled by the conventional digesters from 1952 to date. These changes were accomplished in 1952, after the additional digesters had been placed in service.

The solids content of the digested sludge from the catalytic process for the same period shows a decided improvement when compared with the results obtained from conventional digestion during the period from 1943 through 1951 when a 30-day detention period was the rule. As noted this increase is from 3.8 per cent to 4.9 per cent; however, the latter solids content is somewhat lower than that from the conventional digestion tanks operating at longer detention periods.

Present studies are being undertaken to improve concentration of solids in the digested sludge, at the same time producing a satisfactory supernatant which can be disposed of through the plant. Experiments are now under way using a second concentrator tank into which digested sludge from the acceleration process is pumped and allowed to settle. Special methods of introducing the sludge into the tank are employed so that entrained gas bubbles are quickly liberated. These experiments are not yet complete, but are already giving promise of being able to successfully accomplish the desired results.

The digested sludge from both the conventional and accelerated processes is conditioned with lime and ferric chloride and partially dewatered on vacuum filters prior to incineration. Both sludges react identically insofar as quantities of conditioning chemicals required. Each sludge requires from 10 to 15 per cent lime and 3 to 4 per cent ferric chloride by weight, based on the dry solids content of the sludge. The sludge from the catalytic process, being made up of more finely divided particles, is easier to condition. As a result, a greater volume of sludge can be filtered per unit of time, giving a slightly higher yield per square foot of filter area.

Summary

The catalytic process of sludge digestion has been in successful operation at the Columbus, Ohio, sewage treatment plant, for more than two years. It has demonstrated the practicability of accelerating the digestion of sludge by successfully handling loadings of from two to three times those considered standard for conventional digestion.

The percentage reduction of volatile solids in this high-rate process is comparable to that obtained in conventional digesters, although the loading is double and the detention time is less than one-half as compared with conventional digestion design.

This accelerated process is simple to install and easily controlled. Satisfactory operation has been obtained even though loadings frequently varied up to 100 per cent in excess of designed loading. Scum formation in the accelerated digestion process is negligible. Although satisfactory supernatant is impossible to obtain directly from the tank, indications are that one concentration tank for from two to four primary digesters will solve the problem of digested solids concentration and separation of supernatant.

The process should lend itself to the solution of problems of presently overloaded conventional digesters. When incorporated in the original design of a treatment plant it should effect a considerable savings in capital investment.

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CHEMICAL CONTROL OF DIGESTER SCUM *

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Editor's Note—This summary of published references on digester scum control presents some of the highlights of the problem.

A conceivably ideal method for the elimination of scum in a sludge digester or the prevention of scum formation would be by the addition, either regularly or infrequently, of small quantities of an inexpensive and harmless chemical or chemicals. Unfortunately, such a simple method is not known at this time, although a method may exist.

The scum problem is a common one frequently associated with the operation of conventional sludge digestion tanks. Scum formations as much as 10 ft. in depth have been reported by many sewage treatment plant operators. There are, however, some treatment plants employing separate sludge digestion where the scum problem does not exist. Many of these plants have a mechanical device of some type for the direct or incidental control of scum. Treatment plants which experience no scum trouble and have no mechanical scum control device may hold the key to a simple chemical method for scum control. The answer may be in the chemical analyses of the domestic water. The supernatant liquor of such a plant would be worthy of a comprehensive chemical analysis and a comparison with liquors from digesters where scum occurs.

* Presented at 1955 Annual Meeting, Pacific Northwest Sewage and Industrial Wastes Assn.; Victoria, B. C.; Oct. 27–29, 1955.

Although mechanical scum control methods have been in greater prominence and use during the past decade, especially the past five years, plant observations and laboratory tests have been made on the effect of several chemicals and mixtures on digestion and scum. These are worthy of review.

The digester scum considered in this paper is the digestible type which occurs in most plants and consists of floating fats and greases, and sewage solids which were buoyed to the surface by adherent bubbles of gas. The indigestible scum caused by industrial wastes such as straw, sticks, hair, rags, and feathers can and should be corrected by exclusion or removal of these wastes from the sewage. Some floating material can be expected in any digester, but this scum should be moist and should not retard the release of gas. Its depth should never be more than 24 in.

Ammonia Nitrogen

Schlenz (1)(2) has reported that "ammonia nitrogen" has been used successfully at the Great Lakes Naval Training Station, Great Lakes, Ill., to disperse and control scum which persisted even though the supernatant liquor was recirculated in the digester and discharged into the scum zone. A solution of 100 lb. of ammonium sulfate was fed into the recirculating liquor giving a dosage of about 7 p.p.m. as nitrogen. Six days after the addition of the ammonium sulfate, the scum accumulation disappeared. This method was used for two years. About every three months when the operator considered the scum excessive, the ammonium sulfate was added to the recirculating liquor. Reported cost of this operation was less than $2 for each addition of the chemical.

Schlenz states that (a) if addition of this chemical is too rapid (greater than 50 to 100 lb. per addition), a condition resembling foaming results because of high activity in the scum zone, and (b) excessive additions may be detrimental to the digestion of the scum solids. Additions of about 30 p.p.m. ammonia as nitrogen are recommended in the liquor being recirculated, which is assumed to be one-half of the tank volume.

Gerdel (3) reported that at several sewage treatment plants the addition of an ammonium salt to give 15 to 40 p.p.m. of ammonia in the digester diminished the scum layer and the scum became soft.

Sampson (4) applied ammonium sulfate to a malfunctioning digester at a relatively uniform rate for about two months in an effort to restore normal digester operation. A total of 3,000 lb. of ammonium sulfate, or an average of 50 lb. per day or about 5 p.p.m. as nitrogen was used for the entire digester volume. The ammonium sulfate caused a breakdown of the scum but increased the hydrogen sulfide content of the gas and caused a "foul" odor in the sludge. No improvement was noted in the over-all digestion process; however, other unfavorable factors may have existed.

Four hundred and fifty pounds of anhydrous ammonia were applied to the recirculating digester liquor at a uniform rate over a period of one month. This was equivalent to a daily application of about 7 p.p.m. of nitrogen to the entire digester contents. Lime was also added to the digester at the same time. No mention was made of the effects on the scum. Shortly after the use of the ammonia, well-seeded sludge was added to the digester and operation improvement resulted. It is not known if the ammonia exerted a favorable effect on the digester.

Schlenz (2) believed that the ammonium sulfate provided an essential nutrient which is deficient in the scum and which promotes digester activity and breakup of the scum. Sludge digester liquor contains appreciable amounts of ammonium ion derived mainly from the anaerobic reduction

of proteins. This concentration probably exceeds the recommended addition. For this reason, it appears that the importance of the sulfate ion may be equal to or greater than the ammonium ion.

When sulfate ion is introduced into a digester, an increase in the amount of hydrogen sulfide in the digester gas would be expected. This additional hydrogen sulfide would make the gas more corrosive and/or would dissipate the hydrogen sulfide absorbent more rapidly, necessitating more frequent regeneration of the absorbent in an existing unit or the installation of larger units.

The use of ammonium compounds for scum control was patented as a process in 1947; however, present patent status is not known.

Enzymes and Biocatalysts

For the past five years, claims have been made by manufacturers of enzymes and biocatalysts that these materials can be used to improve almost every phase of sewage treatment. It has been claimed that the addition of a biocatalyst to a digester will reduce scum.

McKee *et al.* (5) reported on the experiences of operators of California sewage treatment plants where several commercial preparations of enzymes and biocatalysts were used. Some plants used one or several preparations in various ways and in different units. Most of the treatment processes were neither benefited nor harmed by the use of the enzymes and biocatalysts. Of the four plant operators who reported the effects on scum in their digesters, two of these indicated no improvement. One plant operator, who reported improvement in the scum condition after the addition of one of the preparations, had also put a mechanical mixer back into service. Scum breakup may have been the result of either or both factors. Another operator used three different commercial preparations, one dry and two liquid. One hundred and fifty pounds of the powdered material was added to the digester in an unspecified period of time. No beneficial effects on digestion were noted but doubt was cast on the test by the statement that the digester scum contained as much as 164 p.p.m. of chromium.

Two hundred and thirty gallons of "a product of vegetable origin" were added to the digester at reasonably uniform rates over a period of about two months, with a report of "a small but short-lived increase in gas production and no other changes in the properties of the digester contents."

Thirteen hundred gallons of a commercial product described as a "supernatant liquor from a digester in which animal and vegetable waste has been completely digested" was added at various levels of the digester in a short period of time, probably within one day. Practically complete scum breakup occurred but no other improvement in digester operation resulted.

Heukelekian and Berger (6) conducted laboratory experiments on sludge digestion using five pure enzymes and a mixture of these five as additives. No improvement or acceleration of digestion was observed. They stated that on a theoretical basis the use of enzymes does not offer a promising outlook, and that the available favorable evidence is not based on rigidly controlled experiments.

Detergents

Because detergents are wetting agents, it appears that scum should be more easily wetted and dispersed if adequate amounts of this material were present in the liquor. Scum particle wetting conceivably could be brought about by the escape of gas at the liquid and scum interface.

The widespread adoption of synthetic detergents for household washing purposes has added 1 to 15 p.p.m. of these materials to sewage (7). There are no indications, however, that digester scum problems have been re-

duced. It would be expected that detergent concentration in the digester would be about equal to that in the raw sewage.

Manganelli (8) reports no improvement in the operation of a digester and a slight reduction in gas when the concentration of detergent was 100 p.p.m. or greater. Lower concentrations of detergent caused some stimulation of gas production, however. This may have resulted from a scum breakup. Fuller (9) observed the effects of 10 household and three industrial detergents on septic tanks at concentrations of 100 p.p.m. in the sewage. He found that six of the septic tanks had a scum blanket equal to the control, six had thinner scum blankets, and one had a thicker scum blanket.

Many anionic detergents, which constitute the largest part of the commercial detergents marketed, contain sulfate derivatives. Additives to the commercial detergents include sodium sulfate. These sulfates would result in an increase in the hydrogen sulfide content of the digester gas.

Phosphates

Sampson (4) fed trisodium phosphate to a digester but obtained no improvement in operation. Rudolfs and Stahl (10) conducted sludge digestion experiments using several inorganic phosphates and two organic phosphate compounds as supplemental nutrients. Except for one test, the phosphorus concentrations were 350 p.p.m. or more. All of the tested phosphates retarded the rate of gas formation and the amount of gas produced. Although volatile matter destruction was decreased, grease destruction may have increased.

Many of the commercial detergent preparations contain soluble sodium phosphates. Apparently, these soluble phosphates, which could be expected to be found in the digester liquor in small concentrations, have had no noticeable effect on digester scum.

Summary and Conclusions

Although considerable information pertaining to scum control by chemicals has been published, the possible lines of investigation are numerous and many aspects of the problem have not been studied.

Reports indicate that ammonium sulfate has been successfully used to control scum in digesters but its use has not been extensive. Biocatalysts and enzymes have created considerable interest as possible scum control agents but field results have not been favorable.

The choice of a scum control method is one of economics. Chemicals may be found to control digester scum but they must be competitive with mechanical methods if they are to be adopted extensively.

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INTERESTING EXTRACTS FROM OPERATION REPORTS

"You have a much better chance of delivering the goods when you're not under the impression you're overburdened"—*San. Eng. News.*

Attention operators! It will be appreciated if copies of all annual reports of both large and small sewage treatment plants are sent to the Federation office for abstracting in this section of the Journal. Please direct annual reports to: Federation of Sewage and Industrial Wastes Associations, 4435 Wisconsin Ave., N.W., Washington 16, D. C.

Annual Report of the Worcester, Mass., Sewage Treatment Plant for the Years 1953 and 1954 *

By Paul C. Hedenstad, *Superintendent, Bureau of Sewers*

This annual report covers the activities of the Bureau of Sewers, including construction and maintenance of sewers, cleaning of catch basins and operation of the sewage treatment plant. Normal operations were hindered by a severe tornado in 1953 that did extensive damage to the community and by two hurricanes in 1954. The latter caused flooding of the Blackstone River which inundated the effluent channel and secondary clarifiers.

Sewer System

Construction of sanitary and storm sewers totaled 12.52 miles in 1953 and 8.48 miles in 1954. The work was done by both private contract and Bureau forces. Developers of residential areas installed sewers under Bureau supervision.

The 15 sewage pumping stations operated normally although they were overtaxed during the hurricanes. Approximately 2.3 cu. yd. of material was removed from each catch basin (storm) at an average cost of cleaning of $2.57 per cubic yard of refuse removed.

During the past five years the sewer system has been extended 50.83 miles with proportionate increases in all appurtenances. An increasing problem is the collapse of sewers due to age. Twenty-five such instances occurred in 1954.

Sewage Treatment

Total flow during 1954 was less than the previous year due to diversion of sewage from the treatment plant as a result of construction work. Over-all efficiency of the plant was 81 per cent for the two-year period. However, in 1954 the removal of suspended solids decreased 14 per cent to 74.1 per cent. This was attributable to the hurricanes.

The continued cooperation of industry in removing acid iron wastes from the sewage effected a satisfactory pH of 6.8, thus insuring proper bacteriological action in the Imhoff tanks and trickling filters. The trickling filters were operated satisfactorily throughout the year.

The quality of the Blackstone River was satisfactory, with a relative stability of 99 per cent and dissolved oxygen at 77 per cent saturation.

All Imhoff tank and clarifier sludge was pumped to a wet well and then to a sludge bed area. Accumulated sludge was removed during the summer by private contract at a cost of $1.37 and $1.32 per cubic yard in 1953 and 1954, respectively.

Table I summarizes the operating data for the two years, 1953 and 1954.

* For last previous extract, see This Journal, **24**, 1, 100 (Jan., 1952).

TABLE I.—Summary of Operating Data, Worcester, Mass., Sewage Treatment Plant for the Years 1953 and 1954

Item	Average 1953	1954
Rainfall, in.	56.80	60.48
Population, connected (est.)	190,000	200,000
Flow (m.g.d.)	32.05	29.07
Grit (cu. ft./m.g.)	2.51	3.27
Cost of removal ($/cu. ft.)	1.09	1.66
Screenings (cu. ft./m.g.)	1.13	1.13
Cost of removal ($/cu. ft.)	0.276	0.46
Imhoff tank skimmings (cu. ft./m.g.)	345	226
Suspended solids (p.p.m.):		
Influent	158	103
Imhoff tank effluent	43	38
New filter effluent	48	33
New secondary tank effluent	17	17
Old filter effluent	55	50
Old secondary tank effluent	30	27
Final over-all removal (%)	88.4	74.1
B.O.D., 5-day (p.p.m.):		
Influent	139	121
Imhoff tank effluent	83	86
New filter effluent	34	28
New secondary tank effluent	20	20
Old filter effluent	38	33
Old secondary tank effluent	25	24
Over-all reduction, new units (%)	84.1	83.0
Over-all reduction, old units (%)	81.0	79.6
pH:		
Influent	6.8	6.8
Imhoff tank effluent	6.8	6.8
New secondary tank effluent	7.0	6.9
Old secondary tank effluent	7.0	6.9
Iron, as Fe (p.p.m.):		
Influent	2.8	2.7
New secondary tank effluent	2.0	1.9
Old secondary tank effluent	2.3	2.0
Imhoff tank sludge:		
Solids (%)	9.7	10.2
Volatile solids (%)	47.62	49.61
Nitrogen as N (p.p.m.)	0.94	1.31
pH	6.5	6.3
Iron (p.p.m.)	1.28	1.17
Clarifier tank sludge:		
Solids (%)	6.69	6.56
Volatile solids (%)	55.85	56.83
Nitrogen as N (p.p.m.)	1.74	1.73
pH	6.8	6.7
Iron (p.p.m.)	1.91	1.44
Operating costs ($):		
Grit chambers	1,178.28	2,087.86
Screening	3,627.41	5,462.79
Imhoff tank	22,728.96	23,701.45
Trickling filters	22,691.34	23,408.86
Secondary tank and clarifiers	17,272.83	18,641.66
Sludge disposal	7,337.34	7,250.90
Laboratory	20,247.24	19,963.79
Sludge removal	29,781.53	21,089.84
General expenses	—	7,174.16
Total	124,864.98	128,781.31
Per million gallons	12.48	12.36
Per capita	0.65	0.64

IDENTIFICATION, PLEASE!*

By J. A. Croes

Worthington Corporation, Harrison, N. J.

The machinery builder is just as much concerned as you are with good service on repair and replacement parts. Accurate identification is the key. Take notice of serial numbers, nameplates, and parts lists—they are used with a purpose. Serial, parts, order, inquiry, and warranty card numbers are coding symbols in systematized business procedures. Failure to use them delays identification or can make identification impossible. Omitting necessary information in orders and letters sets off a chain reaction which necessitates more letters, change orders, and telephone calls.

A better understanding of the purpose of these coding symbols will promote their wider use and thereby save many man-hours.

Why Serial Numbers?

Machinery manufacturers assign serial and part numbers:

1. To keep a record of total number of units produced during any given period;
2. To assist in production planning and shop routing;
3. To facilitate quality control; and
4. To simplify the process of furnishing repairs, spare parts and service.

This fourth reason is very important to both buyer and supplier.

Machines are Individuals

Manufacturers are frequently requested to furnish data on the age and value of machines for customers' accounting purposes. More frequently they are called upon for recommendations concerning the performance or non-performance of a certain unit which may be of such vintage as to be faceless except for a serial number. If the unit bears a serial number, it should always be included with the inquiry. Failure to do so usually results in unnecessary delays. Many manufacturers refuse to furnish parts or information without serial and part numbers, or to assume any responsibility because of the great chance of error.

Supposedly identical machines sometimes have minor differences in their construction. What may seem to be duplicates may sometimes differ radically due to metallurgical differences or other characteristics.

Comprehensive machine records are kept by many machine builders, usually identifiable only by serial numbers. Therein every part furnished for a given serial number is recorded. If necessary, intelligent recommendations can be made to overcome field difficulties or to assist in proper application.

Many users appreciate the value of keeping a record of machine serial numbers. Some resort to the precaution of assigning additional equipment numbers as each new machine is received. Seldom do such users attempt to obtain either parts or advice without first referring to the correct serial number.

In some instances nameplates are removed because corrosive or abrasive atmospheres will obscure the serial number. Under such conditions special nameplates should be used, because the serial number belongs on the machine. Protective adhesives are often helpful. Additional records can be kept if necessary.

A word of caution—nameplates should not be painted over. They frequently are difficult enough to read without being made illegible by several coats of machine enamel. A little care

* Condensed from *Purchasing*, Sept., 1955.

by the painter or a quick wipe with the rag while the paint is still wet will preserve the legibility of the nameplate or other identification tag.

The periodic ritual of shining up the nameplate eventually obscures the serial number. When an emergency arises, the instruction book recording the serial number can't be found. Actually, the nameplate should be polished only when necessary to record its data.

When not sure which of several numbers appearing on the nameplate is the serial number, it's best to list all the possible identifying numbers. Too much data won't get you into trouble, but insufficient data can. You may have omitted the serial number!

Part Numbers

To further simplify the service and inventory problems, manufacturers also use part numbers.

With few exceptions, the manufacturer will furnish a list of parts with his equipment, numbered to correspond with the machine serial number. When ordering or referring to parts, the use of correct names or part numbers positively identifies the part in question.

The parts list that comes with the equipment is your safeguard when ordering parts. A picture can be worth a thousand words—but a proper identification number will save both the words and the picture.

Order Numbering System

When requesting manufacturer's drawings, shipping information, or other details pertaining to an order, it will help if you give him his order number along with your own. His order number is customarily stated in acknowledging your order. This saves time and also compounds the subject identification.

Systems for numbering purchase orders accomplish the following:

1. Identification of purchases or sales quickly.
2. Facilitation of production, and eventual payment.
3. Simplification of cost records.
4. Identification of purchaser's personnel.

Inquiry Numbering Systems

Inquiry or request for bid numbers are used for many of the same reasons as order numbers. Some companies merely add a validating prefix or suffix to the inquiry number when placing the order.

Purchase order numbers are usually issued with a notation to the effect that correspondence pertaining to the order should state the order number. Failure to comply is inconsiderate. Likewise, inquiries often bear the same request. Failure to include the inquiry number sometimes results in quotations being filed without consideration for lack of proper identification. The quotation, and the expense of preparing it, are then wasted.

Warranty Recording Systems

Although not too common in the heavy machinery industry, the warranty card should not be neglected when it is included with the purchase of a new piece of equipment. Warranties provide for:

1. Fixing the date on which the machine guarantee begins and ends.
2. Assuring the purchaser of the benefits of the guarantee because it has been recorded to guide the manufacturer in planning his program to back up his guarantee.

Unless the warranty card is properly filled out and returned as requested, warranty adjustments can be difficult or impossible.

Returned Apparatus (or Material) Systems

When permission to return a product or material to the manufacturer is granted, this is often accompanied by

an identification tag. These tags provide for:

1. Positive identification of incoming material.
2. Initiation of the processes by which proper credit may be issued or work done on material.
3. Establishment of an identification basis for correspondence pertaining to the negotiations concerning the material.

Conclusion

The simplification afforded by taking advantage of established coding systems will end the nightmares of persons who overlook them. If the coding is properly used, the mechanic, stenographer, clerk and engineer are all speaking the same language. When that happens, the chance for error is slight.

Why not get into the habit of using serial numbers, part numbers and order numbers in your communications? Using them will avoid and eliminate much lost time, production, money and embarassment. Those who do not are needlessly adding to their maintenance and operational problems.

TIPS AND QUIPS

Space Waste

Word has been published* that some space-conscious sanitary engineers have been looking to the time of space stations, rocket ships and inter-planetary travel. Operating problems in the limitless space are not all associated with rocket fuels, oxygen supply and other aeronautical considerations. The problem of bodily discharges at conditions of minimal gravitational force must be realistically recognized. The space traveler will need special equipment to keep him from floating around the space ship, but on any extended trip, as space travel must be, the handling of human waste products presents a challenge. It is apparent that pollution of the heavens could be a distinct possibility if the wastes were to be discharged to the outside of the space ship or satellite where they would forever float around in limbo.

There is a definite need for some imaginative thinking about the problem by a 20th Century Jules Verne.

* "Letter to the Editor." *Jour. San. Eng. Div.*, Proc. Amer. Soc. Civil Eng., **82**, SA2 (Apr., 1956).

New York Newsletter

To keep their membership properly informed concerning plans and activities, many progressive Member Associations publish newsletters. These newsletters usually are edited on a bimonthly or quarterly basis by the secretary of the Member Association.

Long a progressive association, the New York Sewage and Industrial Wastes Association has now entered the newsletter circle with "The Gas Vent." At present the publication schedule is semi-annual, but an increased frequency can probably be anticipated.

Sewage Defoamer

New defoamers for use in activated sludge sewage treatment plants have been developed for use on industrial wastes and municipal sewage. The new products are reported to be effective when used in concentrations as small as 1 p.p.m.

Several methods of application were developed during experimental work on the defoamers and are outlined as follows:

1. Direct addition to the aeration tanks by dripping.

2. Pumping through a system of tubing to a large number of aeration tanks.
3. Mixing with a water spray system where additional foam control is necessary.
4. Adding to the influent flow at one point.

Trial and sample quantities are now being made available and can be arranged for by contacting: Swift & Co., Industrial Oil Dept., 1800 165th St., Hammond, Ind.

Drain Tile Clip

Drain tile for septic tank systems or other requirements can be quickly and uniformly spaced through the use of a drain tile clip. The polyethylene clip (Figure 1) has two lugs which fit adjoining tile and provide for proper tile spacing at 3/8 in. In addition, the clip holds the tile in alignment and fits snugly enough to prevent its displacement during trench backfilling. It is no longer necessary to bother with tar paper covering of tile joints or related difficulties. A neat job is assured with a minimum of supervision.

The clip resists the action of acids and alkalies normally found in the soil or domestic sewage. The developers state that the clip will reduce labor costs and that omission of the stone over the tile is feasible.

Price of the new clips is approximately $0.06 each. Information may be obtained from Boco Industries, Inc., 19424 West Eight Mile Rd., Detroit 19, Mich.

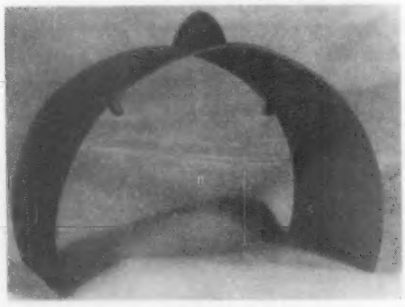

FIG. 1.

Belt Tips

As more automation is incorporated into sewage treatment plant facilities, the conveyor belt becomes a common unit in even the small treatment plant. Most mechanical sludge dewatering equipment utilizes a belt conveyor to transfer the dewatered sludge to a bin, stockpile or dump.

Belt users will wish to check present practice against these suggestions:

1. The belt used should be designed for the materials carried, temperatures encountered and tension required.
2. Belts should be stored out of sunlight, away from hot pipes, stoves and radiators if not installed immediately. When handling belts, slide, roll or lift; don't drop.
3. Thread belt over idlers and pulleys to avoid bending belt sharply. Take care not to drag belt over sharp, rough surfaces. Before belt is run, check for tools left accidentally on return side. Supporting structure should be properly aligned. Misalignment causes crooked running and edge wear.
4. Material should be loaded on belt in the same direction, and at the same speed as belt travel. Load middle of belt, not sides.
5. Loading chute should be permanent, strong, securely fastened. Skirt boards should be used to guide material but should not touch belt. Distance between belt and board should increase in direction of travel so wedged-in lumps will free themselves.
6. Inspect belt for small rips, tears and worn spots before real damage can be done. Particular attention must be given to splices. Belt repair kit should be ready for making prompt repairs.
7. Spilled material should be kept off return side, with metal or wooden decking to prevent lumps from run-

ning between belt and terminal pulley. Brushes or scrapers are beneficial.

8. Continuous records of maintenance and repair cost versus tonnage carried will indicate service quality.

9. Lubricate wisely by checking idlers regularly for adequate grease but avoid excesses which will smear belt and shorten life.

10. Provide means of automatically shutting off preceding belts in a series to prevent pile-ups of material if a following conveyor stops.

11. Develop belt safety rules and provide guards around drives. Prohibit personnel from riding on belts, install frequent shut-off switches, equip belt for harmless discharge of static electricity and control dust at transfer points with exhaust hoods.

An Ill Wind

Summer weather accentuates the odor problems at many sewage treatment plants and summer breezes have a way of wafting uncomplimentary scents far and wide. Frequently it is possible to lessen complaints of odor through judicious operation of the treatment facilities. Odor control precautions might be used, or certain operations delayed, if wind conditions are such that odors would be noticed by adjacent residents. To provide the necessary data for proper planning, a knowledge of wind conditions is necessary. Information can readily be obtained from the local weather bureau or nearby weather station. Better still is the provision of a weather instrument at the sewage treatment plant for convenience and also for additional knowledge of the local weather. Moderately priced equipment is readily available.

Color Code Acknowledgment

The California standard pipe marking and safety color code, which was presented in the June Operator's Corner (THIS JOURNAL, **28**, 6, 813; June, 1956), was the work of the California State Protective Coatings Committee, chairmanned by Glenn Morgan.

Reaction to the publication of the color code material is most favorable, and prospects are good for early action by respective committees of the Federation and the California Member Association. The Safety Committee of the California Association is at present preparing a safety manual for sewage plant operators which will incorporate a color code.

Cooperation by the membership is again invited.

Safety never takes a vacation.

Book Reviews

Handbook of Engineering Materials. EDITED BY DOUGLAS F. MINER AND JOHN B. LEASTONE. John Wiley & Sons, Inc., New York, N. Y. 1,382 pp. Price, $17.50 (1955).

A reference work in which the technical properties of engineering materials takes precedence. Emphasis is placed on the selection and use of material and its adaptability to fabricating methods.

The text is arranged by classes of related or similar materials. The first section provides general information, the second is devoted to ferrous and non-ferrous metals and the third section details non-metals. D. P. SCHIESSWOHL

Industrial Waste Waters (Industrie-Abwässer). BY F. MEINCK, H. STOOF, AND H. KOHLSCHUETTER. Second Edition. Gustav Fischer Publishing House, P. O. Box 431, Stuttgart, Germany. 527 pp., 162 illus. Price, $10.00 (1956).

This revised edition brings up-to-date coverage on the technical aspects of industrial waste treatment. New sections deal with sludge treatment and radioactive wastes. Consideration is given to new processes and the latest results of research in Germany and other countries. A wide range of industrial processes are covered, from a viewpoint that should be of interest to industrial waste people in the United States. D. P. S. AND O. V. F.

Report on Water Resources and Power. Supt. of Doc., U. S. Govt. Printing Off., Washington, D. C. (1955).

This report was prepared for the Commission on Organization of the Executive Branch of Government (Hoover Commission) by the Task Force on Water Resources and Power, Chairmanned by Admiral Ben Moreell. The voluminous and comprehensive works have been published in three volumes.

Volume 1. (271 pp. Price, $1.25)—This volume contains the history of the task force, acknowledgments, dissents and appendices. It includes the following chapters:

Chapter I. Basic Considerations and Findings.
Chapter II. Policies—Past, Present and Future.
Chapter III. Federal Executive Organization—Present and Future.
Chapter IV. Recommendations.
Chapter V. Examples, Facts and Analyses Behind the Recommendations.

Volume 2. (1,002 pp. Price, $3.25)—This volume contains the reports of the several task groups: (a) power generation and distribution; (b) reclamation and water supply; (c) flood control; and (4) improvements to navigation.

Volume 3. (1,782 pp. Price, $2.25)—This volume contains 17 papers prepared by staff consultants and advisors to the Task Force. Among those of particular interest are:

"Inventory of the Federal Agencies Handling Water Resources and Power Development and Conservation," by Perry R. Taylor.

"Federal Gathering of Basic Water Resource Facts," by William G. Hoyt.

"Competition for the Use of Water," by William G. Hoyt.

"The Federal Government and Water Pollution Control," by Keith S. Krause.

"The Relationship of Federal Activities to Municipal and Industrial Water Supply," by Keith S. Krause.

"Patterns of Federal-Nonfederal Partnership in Water Resource Development," by Norvell W. Page.

"Interstate Compacts—The Federal Interest," by Wallace R. Vawter.

"Federal Water Law, 1950–54," by John B. O'Brien, Jr. D. P. SCHIESSWOHL

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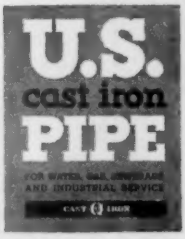

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Proceedings of Member Associations

TEXAS WATER AND SEWAGE WORKS ASSOCIATION

The 1956 Annual Meeting of the Texas Water and Sewage Works Association was held in conjunction with the 28th Annual Short School at Texas A. & M. College, College Station, Tex., March 4–9, 1956. An all-time high in attendance was achieved with an official registration of 790 persons. An excellent program was arranged with a number of national authorities from Texas and other states presenting papers on topics of special interest to this group.

In addition to an excellent short school program for sewage and industrial waste treatment personnel, the following technical papers were presented on the programs of the sewage and industrial wastes sections:

"Deep Sea Waste Disposal—Practices and Effects," a panel discussion by J. W. Eberman, Shell Chemical Corp., Deer Park, and D. W. Hood, Oceanography Dept., Texas A. & M. College.

"Basic Principles of Redox," by Roy E. Weston and W. Eckenfelder, Weston, Eckenfelder and Associates, Newtown Square, Pa.

"Evaluation of Methods Currently Used to Determine B.O.D., C.O.D., O.D., and Odor for Industrial Wastes," by M. B. Ettinger, USPHS, Cincinnati, Ohio.

"Industrial Waste Disposal with a Forward Look," by Robert L. Wright,

(*Continued on page 288a*)

SNOW GATES
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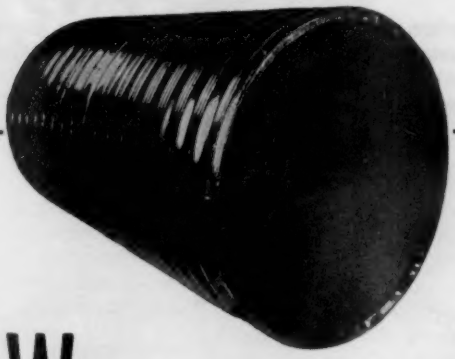

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Carbide and Carbon Chemical Co., Seadrift Plant, Victoria.

"Aerobic Oxidation of Organic Compounds," by Assistant Professor, Ross B. McKinney, M.I.T., Cambridge, Mass.

"A New Coagulant and a New Synthetic Filter Medium (Separan and Dow-Pack)," by R. F. Ryan and Ed. Bryan, Dow Chemical Co., Midland, Mich.

"Application of the Activated Sludge Process for Treatment of Refinery Effluent Waters," by H. F. Elkin, Sun Oil Co., Philadelphia, Pa.

A panel discussion on "Trends in Water Pollution Control," featured visiting state health department engineers.

A program on air pollution progress, instrumentation and analyses was a featured part of the industrial wastes session.

The Arthur Sidney Bedell Award was presented to Joe H. Sorrels, Professor of Civil Engineering, Texas A. & M. College, College Station. Federation Vice-President, John W. Cunningham, attended the meeting but, due to his illness, the Bedell Award was presented by C. H. Connell, Federation Director from Texas.

The following officers were elected to serve the Sewage and Industrial Wastes Section for 1956–57:

Chairman: Glen A. Doty, Breckenridge.
1st Vice-Chairman: E. W. Wallentine, Port Arthur.
2nd Vice-Chairman: Roger Moehlman, Houston.
Secretary: V. M. Ehlers, Austin.
Asst. Secretary-Treasurer: Mrs. E. H. Goodwin, Austin.

Mrs. E. H. Goodwin,
Asst. Secretary-Treasurer

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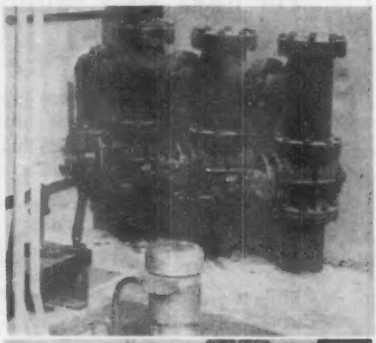

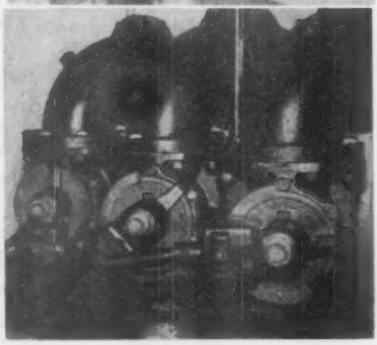

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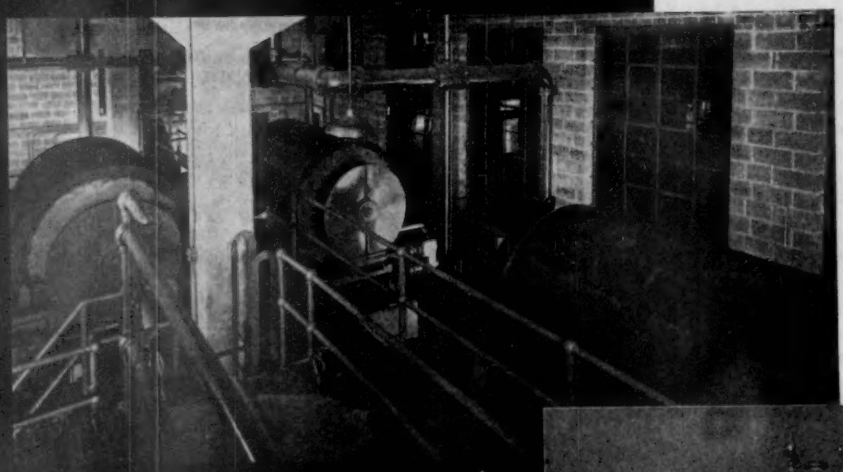
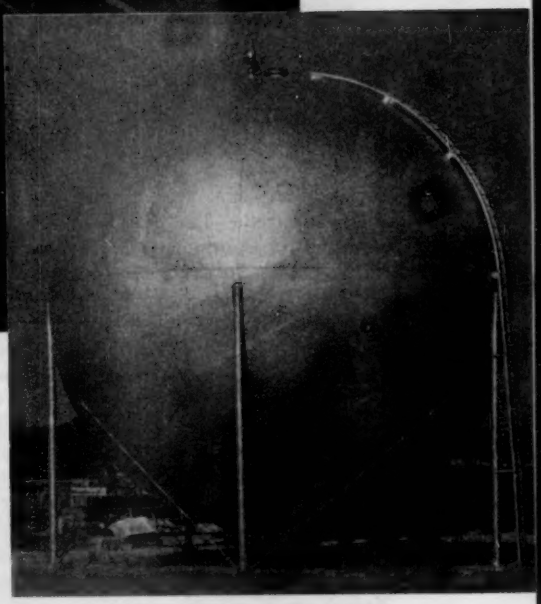


Left: Conkey Sludge Filters dewatering primary sludge.

to prove DEPENDABILITY



Above: 40-ft. diam. Hortonsphere at the St. Joseph Sewage Treatment Plant in St. Joseph, Michigan. It was designed for a working pressure of 40 lbs. per sq in.

The best proof of dependability of any equipment is its service performance. In large and small municipalities throughout the United States, Conkey Sludge Filters are *daily* dewatering more than 2,000 tons of dry solids from sewage and industrial wastes. Hortonspheres® are providing sewage plants with an economical means of storing digester gas under pressure, thus permitting utilization of the gas for fuel in operating the plant. Please write our nearest office for further information on Conkey Sludge Filters and Hortonspheres.

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Centrifugal Pumps—Self-priming electric powered centrifugal pumps with belt or flexible drives are described in literature on industrial pumps.—Rice Pump & Machine Co., Belgium, Wis.

Horizontal Pressure Filter—Bulletin NH–155 describes new features in leaf-type horizontal industrial pressure filters.—Industrial Filter and Pump Manufacturing Co., 5900 Ogden Ave., Chicago 50, Ill.

Jeffrey Products—Booklet No. 888 illustrates the many products, conveyor equipment (chains and accessories), crushers, screens and feeders manufactured.—The Jeffrey Manufacturing Co., Columbus 16, Ohio.

Program Control of Variables—Methods, advantages and applications of program control systems are described in Bulletin 1130.—Minneapolis-Honeywell Regulator Co., Wayne and Windrim Aves., Philadelphia 44, Pa.

Nucleonic Instrumentation—Instruments and equipment for the radiation laboratory are described in literature releases and Catalog No. G–12A.—The Atomic Center for Instruments and Equipment, Inc., 489 Fifth Ave., New York 17, N. Y.

Air Release Valves—Illustrated Bulletin No. 1204 presents information on small air release valves for automatically releasing air accumulations from systems and pipe lines operating under pressure. Essential requirements, installation and operational features are included.—Simplex Valve and Meter Co., 7 East Orange St., Lancaster, Pa.

Pocket-Size Monitor—A battery-powered, pocket-size monitor, described in folder PW 4010, is ideally suited for radioactive tracer and contamination investigations, or checking of "hot" laboratory equipment.—North American Philips Co., Inc., Mount Vernon, N. Y.

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Lime Feeder and Slaker—Bulletin 40–E1B describes dry feeders and lime slakers in both volumetric and gravimetric models.—Omega Machine Co., 345 Harris Ave., Providence, R. I.

pH Buyer's Guide—Modernization of industrial pH instrumentation can be facilitated through the use of Bulletin 425.—Beckman Instruments, Inc., Fullerton, Calif.

Pneumatic Controlled Pumps—Bulletin 955 describes motor driven controlled volume pumps with instrument air-stroke length adjustment. A pneumatic controller varies pump plunger stroke length for varied discharge.—Milton Roy Co., 1300 East Mermaid Lane, Philadelphia 18, Pa.

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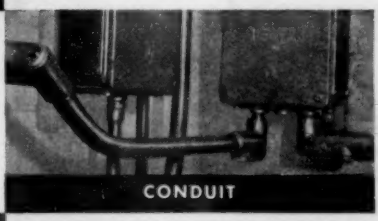

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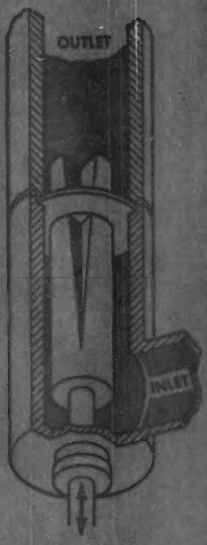
THE WALLACE & TIERNAN

V-NOTCH

variable-orifice

... a new concept for chlorinator control



The W&T V-notch Variable-Orifice is the heart of a new chlorinator control system. With the system, a constant differential vacuum is maintained across the V-notch Variable-Orifice and the flow of chlorine gas is adjusted by varying the area of the orifice.

The W&T V-notch Variable-Orifice has these features:

- Wide range adjustment of chlorine flow
- Excellent reproducibility of flow by a simple adjustment
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As can be seen in the diagram, the V-notch Variable-Orifice is formed by a cylindrical plug positioned inside a matched, circular ring. A V-shaped groove is machined along the length of the plug. The groove starts near one end of the plug and gradually enlarges to its maximum width and depth at the other end of the plug. The V-notch Orifice is formed at the intersection of the grooved plug and the matched ring. The orifice area is varied simply and positively by positioning the plug backward or forward inside the fixed ring.

The V-notch Variable-Orifice is just one design feature of the new W&T V-notch line of Chlorinators. Get all the facts about the W&T V-notch chlorinators before you buy chlorination equipment.

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